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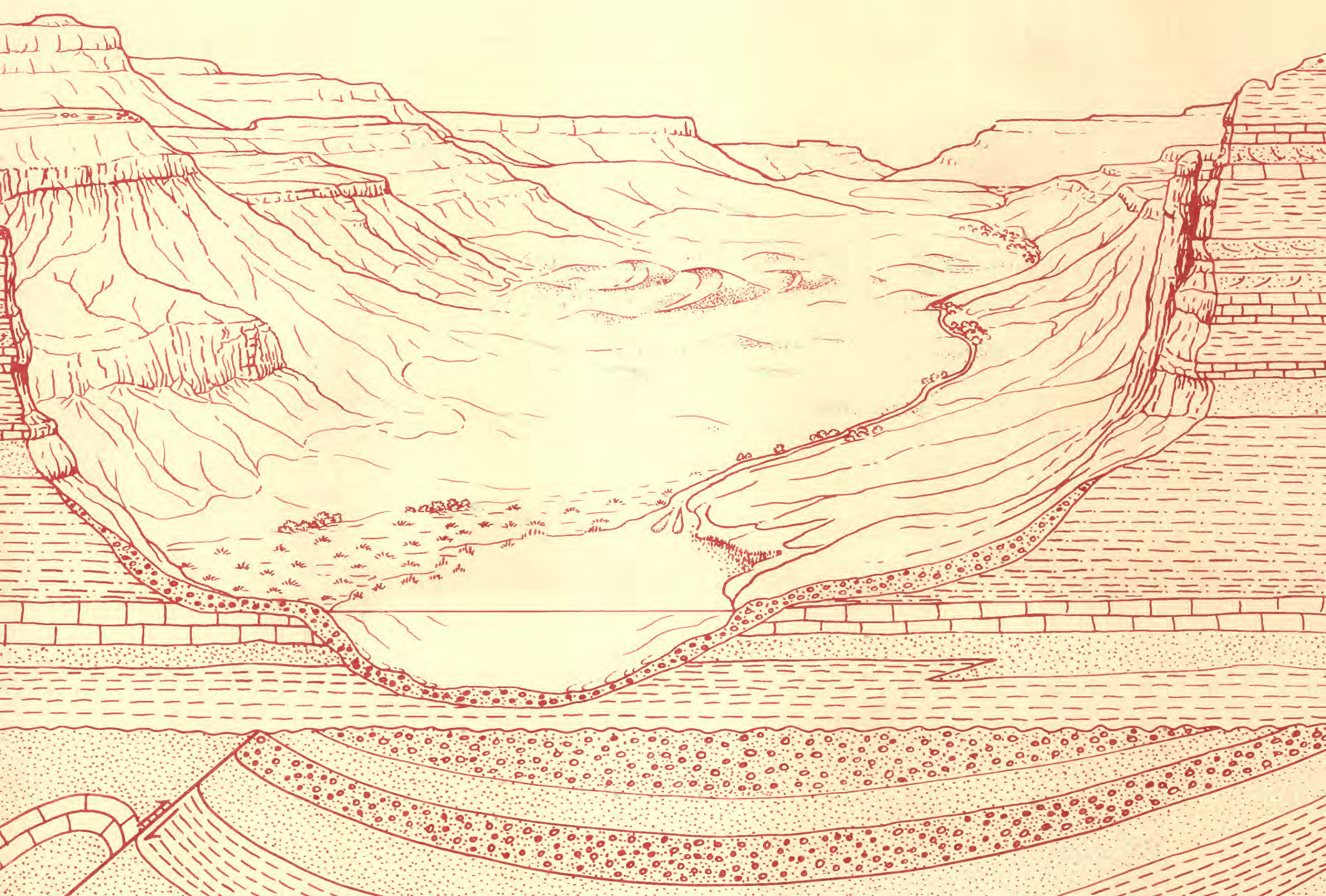
U.S. GEOLOGICAL SURVEY BULLETIN 1839–G, H



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Chapters G and H are issued as a single volume
and are not available separately

U.S. GEOLOGICAL SURVEY BULLETIN 1839–G, H

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
DALLAS L. PECK, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1992

For sale by
Book and Open-File Report Sales
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

(revised for vol. G–H)
Evoluation of sedimentary basins—Appalachian basin.
(U.S. Geological Survey bulletin ; 1839 A–D, G–H)
Includes bibliographies.
Supt. of Docs. no.:19.3:1839–G
Contents: Horses in fensters of the Pulaski thrust sheet, southwestern Virginia / by Arthur P. Schultz—[etc.]—Stratigraphic framework of Cambrian and Ordovician rocks in central Appalachian basin from Morrow County, Ohio, to Pendleton County, West Virginia / by Robert T. Ryder—Depositional environment of the Fincastle Conglomerate near Roanoke, Virginia / by Chrysa M. Cullather.
1. Geology—Appalachian Basin. 2. Sedimentary basins—Appalachian Basin. I. Series.
QE75.B9 no. 1839 A–D 557.3 s 88–600224
[QE78.3] [557.4]

Chapter G

Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Morrow County, Ohio, to Pendleton County, West Virginia

By ROBERT T. RYDER

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

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

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Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Morrow County, Ohio, to Pendleton County, West Virginia

By Robert T. Ryder

Abstract

A 310-mi-long restored stratigraphic cross section between Morrow County, Ohio, and Pendleton County, West Virginia, provides new details of Cambrian and Ordovician stratigraphy in the central Appalachian basin. The cross section shows abrupt eastward thickening of the Cambrian and Ordovician sequence across a northeast-trending fault-controlled hinge zone, which runs along the western margin of the Rome trough and coincides with the Ohio-West Virginia State line. The restored cross section shows that about 5,000 ft of pre-Middle Ordovician structural relief separates Precambrian basement rocks west of the hinge zone from those in the adjoining Rome trough.

West of the Ohio-West Virginia hinge zone, the thickness of the Cambrian and Ordovician sequence is 2,700 to 5,000 ft, whereas, east of the hinge zone in the Rome trough, the thickness of the sequence is 10,500 to 11,300 ft. Sparse subsurface data combined with outcrop data suggest that the Cambrian and Ordovician sequence thins across the eastern margin of the Rome trough before it thickens to about 14,100 ft across a second hinge zone near the Allegheny structural front in Pendleton County, West Virginia.

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 shale unit, and (4) shale and sandstone unit. Each of these units and most associated subunits thicken from west to east across the section.

The sandstone, shale, limestone, and dolomite unit, which is closely associated with the highly block faulted Proterozoic basement terrane, is composed, in ascending order, of the Chilhowee Group, a basal sandstone unit, the Shady Dolomite, the Rome Formation, and the Conasauga Group (part). This part of the sequence is Early and Middle Cambrian in age. The dolomite and sandstone unit forms the core of the Cambrian and Ordovician sequence. In the eastern part of the section, this unit consists, in ascending order, of the Middle and Upper Cambrian Elbrook Dolomite, the Upper Cambrian Gatesburg Formation, and the Lower to lower Middle Ordovician Beekmantown Group. In the Rome trough and the adjoining Ohio-West Virginia hinge zone, the dolomite and sandstone unit consists, in ascending order, of the Upper Cambrian part of the Conasauga Group, the Upper Cambrian Gatesburg Formation, and the Lower to lower Middle Ordovician Beekmantown Group. The well-known Knox unconformity is located at or near the top of the Beekmantown Group.

The limestone and shale unit is the thinnest of the four lithofacies. In ascending order, this unit consists of the Middle Ordovician St. Paul Group, the Middle Ordovician Black River Group, and the Middle and Upper Ordovician Trenton Group. The sandstone and shale unit consists of (1) a lower gray shale unit, the Upper Ordovician Reedsville Shale; (2) a middle argillaceous sandstone at the eastern end of the section, the Upper Ordovician Oswego Sandstone; and (3) an upper red shale, siltstone, and sandstone unit, the Upper Ordovician Juniata Formation and its equivalent Queenston Shale.

INTRODUCTION

The central Appalachian basin in Ohio, West Virginia, and Virginia extends eastward from the Cincinnati

Manuscript approved for publication July 30, 1990.

and Findlay arches on the northwest, across the Rome trough and the Allegheny structural front, to the allochthonous Blue Ridge terrane on the southeast (fig. 1). A concealed part of the basin continues eastward for a minimum of 30 mi beneath the Blue Ridge (Harris and others, 1982; de Witt and Milici, in press).

Oil and gas exploration in the Ohio and West Virginia parts of the basin in the 1960's and 1970's resulted in the drilling of a modest number of holes into or near Precambrian basement rocks (Calvert, 1964, 1965; Perry, 1964; Kornfeld, 1974; Oil and Gas Journal, 1967, 1975, 1976). On the basis of geophysical- and lithologic-log data from these drill holes, I have drawn a 310-mi-long restored stratigraphic cross section through the Cambrian and Ordovician sequence between Morrow County, Ohio, and Pendleton County, West Virginia (section *E–E′*, 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.

The stratigraphic framework of the Cambrian and Ordovician sequence presented here 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 centers around the character of several little-studied lithofacies in the Rome trough segment of the cross section and their correlation with previously described outcrop or subsurface sequences. I have used existing nomenclature wherever possible and have recommended modifications and additions in certain places. Implications of the sedimentary record concerning early Paleozoic evolution of the Appalachian basin and the eastern continental margin of North America are not discussed here.

Previous stratigraphic investigations of the Cambrian and (or) Ordovician Systems that were particularly applicable to my investigation include the work of (1) Calvert (1962, 1963, 1964, 1965), Janssens (1973), Stith (1979), Wickstrom and others (1985), and Wickstrom and Gray (1988) in Ohio; (2) Harris (1959), Prouty and others (1959), Perry (1964, 1971, 1972), Wagner (1966, 1976), and Donaldson and others (1975, 1988) in West Virginia; and (3) Webb (1980) and Sutton (1981) in Kentucky. Information relating to compressional structures that affected Cambrian and Ordovician strata in West Virginia was provided by Gwinn (1964), Jacobeen and Kanes (1975), Perry (1978), Shumaker (1986), Shumaker and others (1985), and Kulander and Dean (1986).

North American time-stratigraphic units following Ross and others (1982) are used here for the Ordovician System rather than the European time-stratigraphic units used by Palmer (1983) and the COSUNA charts (for example, see Patchen and others, 1984). European time-stratigraphic units commonly are not applicable to the Ordovician of North America (Ross and others, 1984). Although Ross and others (1982, 1984) do not apply the formal terms Lower, Middle, and Upper to the Ordovician, I identify them on the time-stratigraphic chart shown in figure 2. Following many Ordovician specialists in North America (for example, Repetski, 1985; Sweet and Bergström, 1986; Shaw and others, 1990), this paper equates the Ibexian (Canadian) Series with the Lower Ordovician, the Whiterockian and Mohawkian Series combined with the Middle Ordovician, and the Cincinnatian Series with the Upper Ordovician.

DRILL-HOLE CONTROL FOR SECTION

Section *E–E′* (pl. 1), the subject of this paper, is one of 12 sections that I have drawn (Ryder, 1987, 1988, 1989) to show the stratigraphic framework of Cambrian and Ordovician rocks across the Appalachian basin from Pennsylvania to Tennessee. The section in this paper is identified as *E–E′* in order to maintain continuity with my previous presentations of Cambrian and Ordovician stratigraphy of the basin. Twelve drill holes ranging from 5 to 60 mi apart and from 4,100 to 20,222 ft in depth constitute the control for section *E–E′* (table 1). Eight of the 12 drill holes penetrated the entire sedimentary cover and bottomed in crystalline basement rocks of Proterozoic age.

Stratigraphic correlations between drill holes are based primarily on geophysical logs, whereas lithofacies patterns between drill holes are based primarily on lithologic logs described by the Geological Sample Log Company (Pittsburgh, Pa.) (table 1) and on cores described by Harris and Flowers (1956) and Ryder (1988, 1989, in press). The lithologic character of the basal sandstone unit, the Shady Dolomite, and the Rome Formation has been generalized east of the Rome trough from outcrop studies by Rader and Biggs (1975) and others in adjoining northern Virginia between the North Mountain fault and the Blue Ridge (fig. 1).

Section *E–E′* has been restored to a horizontal datum located in the middle of the unnamed argillaceous limestone of the St. Paul Group in West Virginia (pl. 1). At the western end of section *E–E′* in Morrow County, Ohio, the datum is located at the base of the Black River Limestone or, in local oil industry terminology, the base of the Gull River Formation (Ryder, in press).

The United Fuel No. 8800–T Sponaugle (UFS) drill hole (no. 12, fig. 1, pl. 1, table 1), located at the eastern end of section *E–E′*, has been moved about 8 mi east of its present location to account for westward tectonic transport along an underlying thrust fault (Perry, 1964; Jacobeen and Kanes, 1975; Shumaker and others, 1985). In addition, drilled thicknesses of stratigraphic units in the UFS drill hole were restored to the approximate true thicknesses calculated by Perry (1964). Thicknesses of Upper Ordovician formations in the vicinity of the UFS drill hole were obtained from outcrop sections described by Prouty (1927) and Perry (1971).

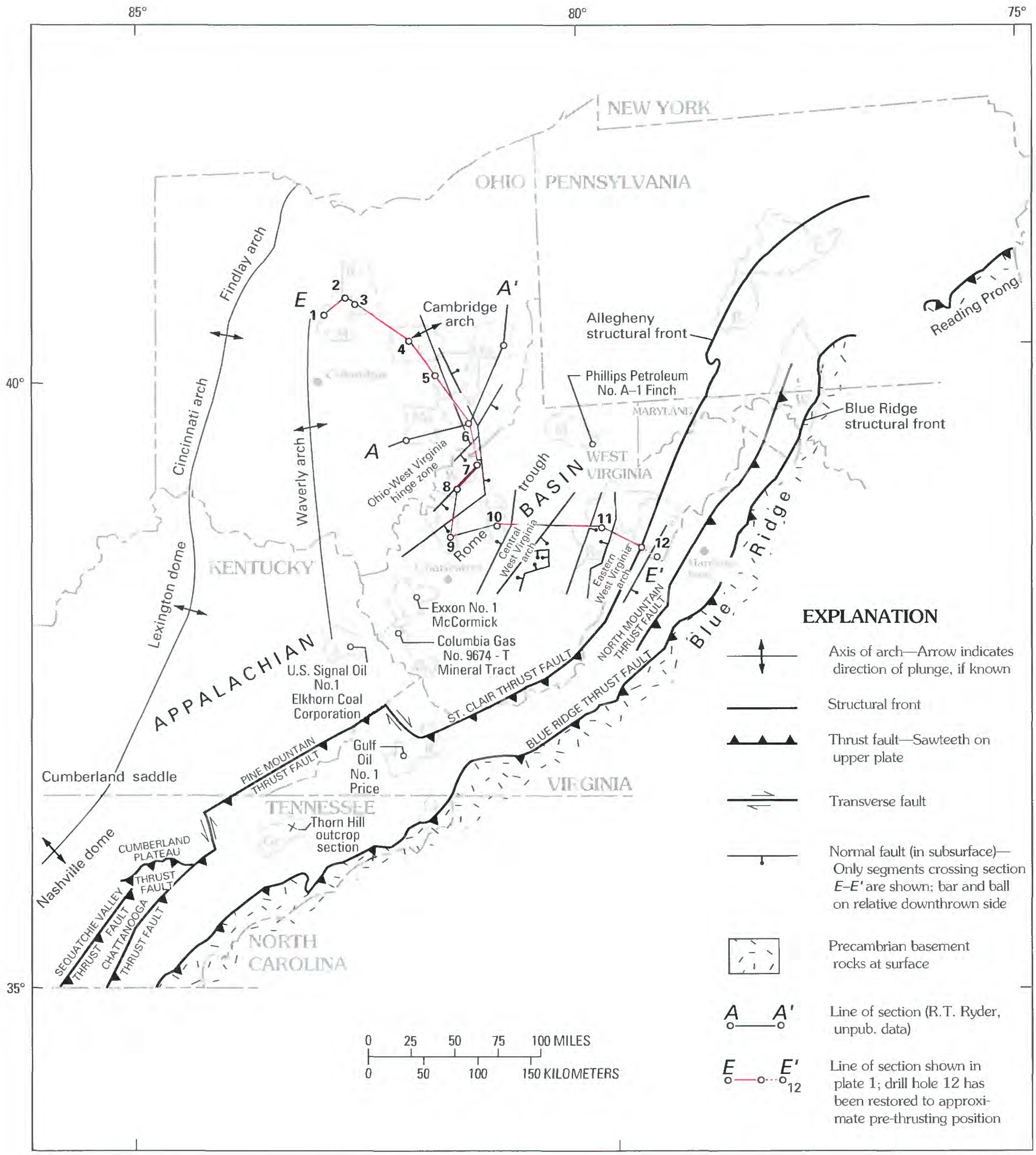


Figure 1. Tectonics of Ohio, West Virginia, and adjoining States, showing the Appalachian basin, section *E–E'*, selected drill holes, and selected counties. Base from Wallace and de Witt (1975). Major tectonic and geologic features are from Cooper (1945), Woodward (1961), Calver and Hobbs (1963), Swingle and others (1966), Rodgers (1970), and Wallace and de Witt (1975). Numbered drill holes in section *E–E'* are identified in table 1. Selected counties are identified as follows. Kentucky—J, Johnson. Maryland—W, Washington. Ohio—C, Coshocton; G, Guernsey; Ha, Harrison; M, Morrow; Mo, Morgan; N, Noble; R, Richland. Pennsylvania—B, Blair; C, Centre; F, Franklin. Tennessee—G, Grainger; J, Johnson. Virginia—R, Russell. West Virginia—Ca, Calhoun; J, Jackson; L, Lincoln; M, Marion; Mn, Mingo; P, Pendleton; Ra, Randolph; W, Wood.

Table 1. Drill holes used in section *E–E'*

Identification no.	Name used in text (abbreviation)	Location	Permit no.	Lithologic log[1]	Cored intervals (ft) and formation	Total depth (ft)	Age of oldest rock penetrated (formation)
			Ohio				
1	United Producing No. 3 Myers (UPM)	Canaan Township, Morrow County	12	GSLC	2,978–3,079.5; Knox Dolomite	4,100	Middle Proterozoic.
					4,090–4,100; basement rocks of Middle Proterozoic age.		Middle Proterozoic.
2	Pan American No. 1 Windbigler (PAW)	Troy Township, Morrow County	47	GSLC	3,853–3,883.5; Black River Limestone, Wells Creek Formation, Knox Dolomite.	4,890	Middle Proterozoic.
3	Pan American No. 1 Palmer (PAP)	Troy Township, Richland County	289		4,160–4,284; Black River Limestone, Wells Creek Formation, Knox Dolomite.	4,775	Late Cambrian (Rome Formation of Janssens (1973)).
4	Tatum No. 1 Lee (TL)	Jefferson Township, Coshocton County.	2053	GSLC		6,970	Middle Proterozoic(?).
5	Lakeshore Pipeline No. 1 Marshall (LM)	Adams Township, Guernsey County	782	GSLC	6,875–7,045; Black River Limestone, Wells Creek Formation, Knox Dolomite, Rose Run Sandstone.	8,602	Middle Proterozoic.
6	Amerada No. 1 Ullman (AU)	Elk Township, Noble County	1278	GSLC		11,442	Middle Proterozoic.
			West Virginia				
7	Hope Natural Gas No. 9634 Power Oil Company (HNGP).	Walker District, Wood County	351	GSLC	7,667–7,860; Tuscarora Sandstone, Juniata Formation.	13,331	Middle Proterozoic.
					9,416–9,665; Trenton Group		Middle Proterozoic.
					9,790–11,684; Black River Group, St. Paul Group, Beekmantown Group, Gatesburg Formation.		Middle Proterozoic.
					11,923–11,962; Gatesburg Formation		Middle Proterozoic.
					13,004–13,171; Rome Formation		Middle Proterozoic.
					13,310–13,327; basement rocks of Middle Proterozoic age.		Middle Proterozoic.
8	Exxon No. 1 Deem (ED)	Steele District, Wood County	756	GSLC	12,445–12,473.5	13,266	Middle Proterozoic.
					12,585–12,604; Rome Formation		Middle Proterozoic.
9	Exxon No. 1 McCoy (EM)	Washington District, Jackson County.	1366	GSLC	9,235–9,326; Black River Group	17,675	Middle Proterozoic.
					13,978–14,000		Middle Proterozoic.
					14,061–14,153		Middle Proterozoic.
					14,358–14,418		Middle Proterozoic.
					15,508–15,567.5; Conasauga Group		Middle Proterozoic.
					16,441–16,502; Rome Formation		Middle Proterozoic.
10	Exxon No. 1 Gainer-Lee (EGL)	Center District, Calhoun County	2503			20,222	Middle Proterozoic.
11	Hope Natural Gas No. 10,228 West Virginia Medium Security Prison Farm (HNGPF).	Huttonsville District, Randolph County.	103	GSLC		13,121	Middle Ordovician (St. Paul Group).
12	United Fuel No. 8800–T Sponaugle (UFS)	Circleville District, Pendleton County.	6	GSLC, UFGC	12,515–12,527; Black River Group	13,001	Middle and Late Cambrian (Elbrook Dolomite) thrust over Middle and Late Ordovician (St. Paul, Black River, and Trenton Groups).

[1] Lithologic logs from Geological Sample Log Company (GSLC), Pittsburgh, Pa., and United Fuel Gas Company (UFGC).

Upper and Middle Ordovician strata penetrated in the Hope Natural Gas No. 10,228 West Virginia Medium Security Prison Farm (HNGPF) drill hole (no. 11, fig. 1, pl. 1, table 1) are also allochthonous (Gwinn, 1964; Shumaker and others, 1985), but minor palinspastic restoration was needed because of the 1 mi or less of net westward tectonic transport. Drilled bed thicknesses of Upper Ordovician formations in the HNGPF drill hole were converted to their approximate true thicknesses by removing duplicated intervals caused by minor thrust faults (Gwinn, 1964; Shumaker and others, 1985).

Except for Middle and Upper Ordovician faunas described in the Hope Natural Gas No. 9634 Power Oil Company (HNGP) drill hole (no. 7, fig. 1, pl. 1, table 1) by Prouty and others (1959) and in outcrop in Pendleton County, West Virginia, by Kay (1956) and Bretsky (1970), paleontologic control is lacking in section *E–E′*. Consequently, ages are assigned to stratigraphic units in section *E–E′* by correlating the units with paleontologically dated horizons that occur in (1) adjoining drill holes, (2) thrust-faulted strata along the eastern margin of the basin, and (3) gently warped strata along the western margin of the basin.

BASEMENT STRUCTURE

Details of the block-faulted Proterozoic basement rocks underlying West Virginia and adjoining Ohio are only beginning to be understood. Normal faults and associated fault blocks that intersect section *E–E′* (fig. 1, pl. 1) are based on limited data and, for this reason, are shown as 25- to 50-mi-long incomplete segments in figure 1. Undoubtedly, these structural features will be modified as more multifold seismic records are published and as wells in and east of the Rome trough are drilled to the Proterozoic basement. The block-faulted Precambrian basement rocks along section *E–E′* (fig. 1, pl. 1) resulted largely from Middle Cambrian extensional tectonism (Read, 1989). Post-Cambrian tectonic events may have reactivated these faults, as they have done in eastern Kentucky (Sutton, 1981), but the restoration of section *E–E′* to a horizontal datum in the lower part of the Middle Ordovician sequence has removed most post-Cambrian basement offset. According to Beardsley and Cable (1983), block faulting of the basement beneath West Virginia may have been controlled by normal dip-slip motion along preexisting thrust faults.

Basement rocks in West Virginia and adjoining Ohio consist largely of metamorphic rocks of Grenville age (1.0 Ga; Middle Proterozoic) (Bass, 1959, 1960; Gates and Watson, 1975). These basement rocks have been highly block faulted both within and east of a northeast-trending hinge zone whose position approximately coincides with the Ohio-West Virginia State line. The hinge zone, which consists of several closely spaced normal faults, is identified in this paper as the Ohio-West Virginia hinge zone (fig. 1, pl. 1) and coincides with the Middle Cambrian hinge of Read (1989). Before the deposition of the datum horizon in Middle Ordovician time, about 5,000 ft of structural relief occurred along section *E–E′* between the Middle Proterozoic basement rocks west of the Ohio-West Virginia hinge zone and those to the east in the adjoining Rome trough (pl. 1). In contrast, the present structural relief of basement rocks across the Ohio-West Virginia hinge zone, in the vicinity of section *E–E′*, is about 8,000 ft (Cardwell, 1977). I suggest that the majority of the post-Middle Ordovician increase in structural relief has resulted from the reactivation of basement faults during middle and late Paleozoic compressional events. Individual faults that constitute the hinge zone can be identified on multifold seismic records (Beardsley and Cable, 1983; Shumaker, 1986; Morris, 1989), and the hinge zone as a whole can be identified on the aeromagnetic map shown by King and Zietz (1978).

West of the hinge zone in eastern Ohio, the Grenville-age 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 within and east of the hinge zone. Near the western end of section *E–E′*, a major arch that involves basement rocks in north-central Ohio plunges southward into northeastern Kentucky. This arch was named the Waverly arch (fig. 1) by Woodward (1961); very likely, it is controlled by basement faults. The Cambridge arch, a low-relief monoclinal feature in southeastern Ohio (fig. 1), also may have been controlled by basement faulting (Shumaker, 1986).

The three northeast-trending, down-to-the-east normal faults that compose the hinge zone along section *E–E′* (fig. 1, pl. 1) are based on abrupt thickness changes in the lower part of the Cambrian and Ordovician sequence rather than on geophysical evidence. Of these three faults, the one located between the Exxon No. 1 Deem (ED) (no. 8, fig. 1, pl. 1, table 1) and the Exxon No. 1 McCoy (EM) (no. 9, fig. 1, pl. 1, table 1) drill holes has created the maximum vertical separation of basement rocks (fig. 1, pl. 1). Harris (1975, 1978), Beardsley and Cable (1983), Shumaker (1986), and Donaldson and others (1988) also have identified a major fault, in approximately this location, that they consider to be the western border fault of the Rome trough. Beardsley and Cable (1983) have suggested that this fault is one of several en echelon normal faults that define the western margin of the Rome trough in West Virginia and Ohio. The fault pattern shown in figure 1 resembles the distribution of the left-stepping en echelon faults described by Beardsley and Cable (1983). A north-trending, down-to-the-east normal fault near the eastern end of Wood County, W. Va. (Shumaker, 1986; Morris, 1989), also has strongly influenced the configuration of the western margin of the Rome trough (fig. 1).

Throughout most of its extent in West Virginia, the Rome trough is bounded on the east by a conspicuous northeast-trending positive magnetic anomaly (King and Zietz, 1978; Kulander and Dean, 1978). King and Zietz (1978) have identified this magnetic anomaly as part of the New York-Alabama lineament, and Kulander and Dean (1978, 1986) have identified the tectonic feature that produced the anomaly as the Central West Virginia arch (fig. 1, pl. 1). Following Shumaker and others (1985), I interpret this positive tectonic feature to be a horst block.

A 60-mi-wide area east of the Central West Virginia arch on the magnetic maps of King and Zietz (1978) and Kulander and Dean (1978) is characterized by conspicuous northeast-trending linear anomalies that closely resemble those anomalies associated with the Rome trough and adjoining horst blocks. I interpret this area as a block-faulted terrane. Basement structures interpreted in the block-faulted terrane east of the Central West Virginia arch consist of a narrow graben located beneath the HNGPF drill hole and an adjoining horst block—the Eastern West Virginia arch of Kulander and Dean (1978, 1986), the eastern margin of which is located beneath the Allegheny structural front (fig. 1, pl. 1). The Eastern West Virginia (horst) arch, in conjunction with the adjoining graben east of the Allegheny structural front, probably represents an additional hinge zone along section *E–E′*. This proposed hinge zone coincides with the Early Cambrian hinge of Read (1989). The down-to-the-east normal fault that bounds the eastern side of the proposed hinge zone, along which Middle Proterozoic basement rocks have been offset as much as 1,800 ft, was first interpreted by Jacobeen and Kanes (1975) from seismic data.

THICKNESS CHANGES IN CAMBRIAN AND ORDOVICIAN SEQUENCE

From west to east, the Cambrian and Ordovician sequence along section *E–E′* shows about a sixfold increase in thickness (pl. 1). This magnitude of thickening is based on (1) the 2,700-ft-thick Cambrian and Ordovician sequence that was penetrated in the United Producing No. 3 Myers (UPM) drill hole (no. 1, fig. 1, pl. 1, table 1) at the western end of the section and (2) the estimated 14,100-ft-thick Cambrian and Ordovician sequence at the eastern end of the section, which was penetrated in part by the UFS drill hole at the eastern end of the section.

East of the fault-controlled Ohio-West Virginia hinge zone (pl. 1), much of the total thickening of the sequence has occurred in the Lower and Middle Cambrian rocks located at the base of the sequence. Documentation for the ages assigned in this section is presented in the following discussion of the stratigraphic framework. The abrupt thickening of the Lower and Middle Cambrian strata at the base of the sequence is best documented between the HNGP and the Exxon No. 1 Gainer-Lee (EGL) (no. 10, fig. 1, pl. 1, table 1) drill holes, which have penetrated about 350 and 3,400 ft of these strata, respectively (pl. 1). A proposed down-to-the-east normal fault between the HNGP and the Amerada No. 1 Ullman (AU) (no. 6, fig. 1, pl. 1, table 1) drill holes marks the approximate eastern limit of Lower and Middle Cambrian strata along section *E–E′* (pl. 1).

The Lower and Middle Cambrian sequence extends east of the Rome trough, but its thickness is less certain. I suggest that, east of the Rome trough, this sequence thins across the Central West Virginia arch to about 2,000 ft and then expands again to about 5,600 ft near the Allegheny structural front (pl. 1).

Upper Cambrian strata and overlying Ordovician strata constitute an eastward-thickening wedge of rocks that extends the length of section *E–E′*. This part of the total sequence expands eastward from 2,700 ft in the UPM drill hole, to 5,200 ft in the HNGP drill hole, to about 8,500 ft near the UFS drill hole (pl. 1).

Most of the eastward thickening of the Upper Cambrian through Upper Ordovician sequence was depositional. However, some eastward thickening of this sequence was produced by the westward truncation of progressively older strata beneath the Knox unconformity (Harris, 1959; Mussman and others, 1988; Ryder, in press). For example, in Morrow County, Ohio, at the western end of section *E–E′*, Lower Ordovician rocks have been completely truncated by the Knox unconformity, so that Middle Ordovician rocks rest directly on Upper Cambrian rocks (Calvert, 1965; Dolly and Busch, 1972).

STRATIGRAPHIC FRAMEWORK

Basal Sandstone Unit and Shady Dolomite (Lower Cambrian)

A 50- to 100-ft-thick basal sandstone and subordinate gray shale unit and an overlying 300-ft-thick limestone and gray shale unit, present in the EM and EGL drill holes, are the oldest drilled sedimentary rocks in section *E–E′* (pl. 1). The sandstone and shale unit rests unconformably on Middle Proterozoic granitic basement rocks of Grenville age and is overlain conformably by the limestone and gray shale unit. The top of the limestone unit is possibly an unconformity.

The basal sandstone-dominated unit correlates with a sandstone in the Rome trough of eastern Kentucky that has been identified as the Basal Sand by Thomas (1960) and Sutton (1981), the Basal Sandstone by McGuire and Howell (1963), and the Basal Arkose by Webb (1980). Patchen and others (1984) and Donaldson and others (1988) applied the terms basal sandstone and Basal Arkose, respectively, to correlative sandstone units in the Rome trough of West Virginia. The Basal Sandstone of McGuire and Howell (1963) and the basal sandstone of Patchen and others (1984) are retained in this investigation as the basal sandstone unit.

The overlying limestone and gray shale unit correlates with a sequence dominated by dolomite and limestone in the Rome trough of eastern Kentucky, which was identified as the Tomstown Dolomite by Thomas (1960) and Sutton (1981), the Shady-Tomstown(?) Dolomite by McGuire and Howell (1963), and the Shady Dolomite by Webb (1980). Moreover, the limestone and gray shale unit correlates in the Rome trough of West Virginia with a carbonate sequence that has been identified as the "Tomstown" Dolomite and the Shady Limestone by Patchen and others (1984) and Donaldson and others (1988), respectively. The name Shady Dolomite as applied by Webb (1980) is preferred here because the limestone and shale unit and equivalent dolomite(?) units in section *E–E′* are correlated more easily—through the Columbia Gas No. 9674–T Mineral Tract (Mingo County, West Virginia) and the Gulf Oil No. 1 Price (Russell County, Virginia) drill holes (fig. 1)—with the type locality of the Shady Dolomite in Johnson County, Tennessee (Keith, 1903), than with the type locality of the Tomstown Dolomite in Franklin County, Pennsylvania (Stose, 1906). Where limestone is predominant over dolomite, as in the limestone and shale unit, the name limestone of the Shady Dolomite is applied.

The basal sandstone-Shady Dolomite interval is interpreted in section *E–E′* to extend as far east as the Allegheny structural front (pl. 1). East of the Allegheny structural front, the basal sandstone unit and the Shady Dolomite interval presumably correlate with the uppermost part of the Lower Cambrian Chilhowee Group and the Lower Cambrian Shady Dolomite that crops out in northern Virginia between the North Mountain fault and the Blue Ridge, respectively (figs. 1, 2) (Butts, 1940; King, 1950; Brent, 1960; Rader, 1982).

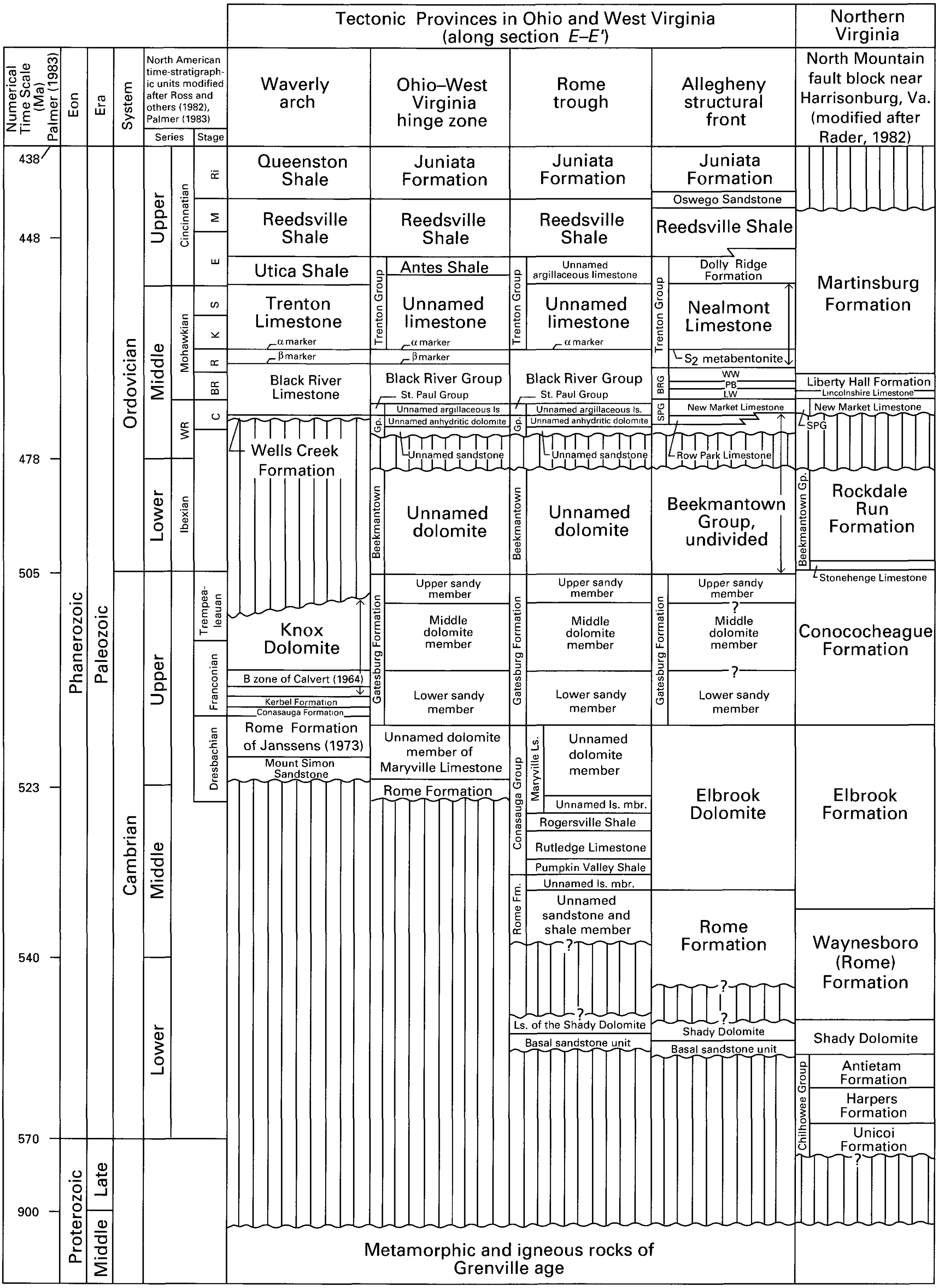
I interpret the basal sandstone-Shady Dolomite sequence shown in section *E–E′* as a transgressive sequence that postdates deposition of the estimated 1,800-ft-thick Lower Cambrian Chilhowee Group and the major down-to-the-east normal fault of Jacobeen and Kanes (1975) east of the Allegheny structural front (fig. 1). Normal faults between the Eastern and Central West Virginia arches of Kulander and Dean (1978) possibly were initiated during the latest phase of Chilhowee deposition in middle Early Cambrian time, but their movement largely postdated deposition of the basal sandstone-Shady Dolomite sequence in latest Early Cambrian time. Normal faults that bound the Rome trough and involve the basal sandstone-Shady Dolomite interval are considered here to be latest Early to early Middle Cambrian in age.

Rome Formation (Lower and Middle Cambrian)

A 1,000- to 1,100-ft-thick sequence of sandstone and gray, green, and red shale, capped by a 300-ft-thick argillaceous limestone unit, overlies the limestone of the Shady Dolomite in the Rome trough segment of section *E–E′* (fig. 2). The contact between the Shady Dolomite and the overlying gray, green, and red shale is possibly unconformable. The sandstone and shale sequence correlates with a lithologically similar unit in the Rome trough of eastern Kentucky that has been identified as (1) the lower part of the Rome Formation by Thomas (1960) and McGuire and Howell (1963), (2) the Rome Formation by Webb (1980), and (3) the Elk Horn shale of the Rome by Sutton (1981). The overlying limestone unit correlates with a limestone unit in the Rome trough of eastern Kentucky that has been identified as part of the Rome Formation by McGuire and Howell (1963) and the lower Rome limestone by Sutton (1981). In the Rome trough of southwestern West Virginia, the sandstone and shale unit in section *E–E′* correlates with a shale-dominated unit in the Columbia Gas No. 9674–T Mineral Tract drill hole (fig. 1) that Donaldson and others (1988) correlated with the Rome Formation and the overlying Pumpkin Valley Shale of the Conasauga Group. In addition, the limestone unit in section *E–E′* correlates with a limestone unit in the Columbia Gas No. 9674–T Mineral Tract drill hole that Donaldson and others (1988) identified as the Rutledge Limestone of the Conasauga Group.

The sandstone and shale and the limestone units in section *E–E′* are assigned here to the Rome Formation. The sandstone and shale unit is identified informally as the unnamed sandstone and shale member, and the limestone unit is identified informally as the unnamed limestone member (pl. 1, fig. 2). My definition of the Rome Formation closely follows that of Webb (1980) and Donaldson and others (1988), except that it also includes the informal lower Rome limestone of Sutton (1981), the limestone that Donaldson and others (1988) identified as Rutledge Limestone, and the shale that Donaldson and others (1988) identified as Pumpkin Valley Shale. The Rome Formation recognized here is equivalent to approximately the lower one-half of the Rome Formation (Limestone) of Thomas (1960), McGuire and Howell (1963), and Sutton (1981) in eastern Kentucky.

An assemblage of fossils consisting of brachiopods, trilobites and mollusks was recovered from a cored sequence (17,906 to 17,915 ft) in the Columbia Gas No. 9674–T Mineral Tract drill hole (Donaldson and others, 1975,1988). Donaldson and others (1988, p. 9) stated that "the fossil data indicate an age of Middle Cambrian for these shales although the possibility of a Late Cambrian age also is possible." This cored sequence of shale and siltstone is within the Rome Formation of Donaldson and others (1988) and correlates with the lower one-third of my Rome Formation in the EM and EGL drill holes (pl. 1). Therefore, judging from these fossil data, I consider the Rome Formation in the Rome trough segment of section *E–E′* to be Middle Cambrian in age (pl. 1, fig. 2). However, a late Early Cambrian age cannot be ruled out.


Tectonic Provinces in Ohio and West Virginia (along section E–E')
Northern Virginia
Numerical Time Scale (Ma) Palmer (1983)
Eon
Era
System
North American time-stratigraphic units modified after Ross and others (1982), Palmer (1983)
Series
Stage
Waverly arch
Ohio–West Virginia hinge zone
Rome trough
Allegheny structural front
North Mountain fault block near Harrisonburg, Va. (modified after Rader, 1982)
438
448
478
505
523
540
570
900
Phanerozoic
Proterozoic
Paleozoic
Late
Middle
Ordovician
Cambrian
Upper
Middle
Lower
Cincinnatian
Mohawkian
Ibexian
WR
Ri
M
E
S
K
R
BR
C
Trempealeauan
Franconian
Dresbachian
Queenston Shale
Juniata Formation
Oswego Sandstone
Reedsville Shale
Utica Shale
Antes Shale
Unnamed argillaceous limestone
Dolly Ridge Formation
Trenton Limestone
Unnamed limestone
Nealmont Limestone
Martinsburg Formation
Trenton Group
α marker
β marker
S2 metabentonite
Black River Limestone
Black River Group
St. Paul Group
WW
PB
LW
BRG
SPG
Liberty Hall Formation
Lincolnshire Limestone
New Market Limestone
Unnamed argillaceous ls
Unnamed anhydritic dolomite
Gp.
Wells Creek Formation
Unnamed sandstone
Row Park Limestone
Beekmantown
Beekmantown Gp.
Unnamed dolomite
Beekmantown Group, undivided
Rockdale Run Formation
Stonehenge Limestone
Knox Dolomite
B zone of Calvert (1964)
Kerbel Formation
Conasauga Formation
Gatesburg Formation
Upper sandy member
Middle dolomite member
Lower sandy member
Conococheague Formation
Rome Formation of Janssens (1973)
Mount Simon Sandstone
Unnamed dolomite member of Maryville Limestone
Rome Formation
Conasauga Group
Maryville Ls.
Unnamed dolomite member
Unnamed ls. mbr.
Rogersville Shale
Rutledge Limestone
Pumpkin Valley Shale
Elbrook Dolomite
Elbrook Formation
Rome Fm.
Unnamed sandstone and shale member
Waynesboro (Rome) Formation
Ls. of the Shady Dolomite
Shady Dolomite
Basal sandstone unit
Chilhowee Group
Antietam Formation
Harpers Formation
Unicoi Formation
?
Metamorphic and igneous rocks of Grenville age

At the western margin of the Rome trough, the Rome Formation climbs abruptly upsection at the expense of five units of the overlying Conasauga Group and steps westward across progressively higher fault blocks of the adjoining Ohio-West Virginia hinge zone. The most abrupt thickening of the Rome Formation occurs between the EM drill hole and the easternmost fault of the hinge zone, where the Rome thickens from 1,300 to about 3,000 ft at the expense of the Conasauga (pl. 1). The 320- to 1,100-ft-thick Rome Formation that occupies the Ohio-West Virginia hinge zone west of the ED drill hole probably terminates against one of the westernmost faults of the hinge zone (pl. 1). The uppermost sandstone unit of the Rome apparently extends west of the Ohio-West Virginia hinge zone, where it rests on Middle Proterozoic basement rocks. It was named the Mount Simon Sandstone (Upper Cambrian) by Cohee (1948).

The thickness and lithology of the undrilled Rome Formation east of the Rome trough are estimated from (1) the interpreted geometry of basement-involved fault blocks (fig. 1) and (2) published outcrop descriptions of the Rome and Waynesboro Formations in northern Virginia between the North Mountain fault and the Blue Ridge (King, 1950; Edmundson and Nunan, 1973; Gathright and Nystrom, 1974). These data suggest that, east of the Rome trough, the Rome Formation and equivalent units thin abruptly across the Central West Virginia arch before they thicken eastward to an estimated 1,600 ft near the Allegheny structural front (pl. 1). The lower 1,050 ft of the estimated 1,600-ft-thick sequence near the Allegheny structural front is probably dominated by sandstone and shale that is equivalent to, or older than, the unnamed sandstone and shale member in the Rome trough. In contrast, the upper 550 ft of the estimated 1,600-ft-thick sequence near the Allegheny structural front is dominated by dolomite that correlates with the unnamed limestone member of the Rome Formation in the Rome trough (pl. 1).

Rader and Biggs (1975) concluded that the carbonate-dominated upper part of the Rome Formation of Edmundson and Nunan (1973) and Gathright and Nystrom (1974) in northern Virginia correlates with the lower part of the Elbrook Formation (Middle Cambrian) in southern Pennsylvania. Consequently, Rader and Biggs (1975) reassigned the part of the Rome Formation dominated by carbonate to the lower part of the Elbrook Formation and assigned the name Waynesboro (Rome) Formation to the part of the Rome Formation dominated by sandstone and shale. In the area between the Central West Virginia arch and the Allegheny structural front, I follow Rader and Biggs (1975) and (1) restrict the Rome Formation to the sandstone and shale sequence and (2) assign the predominantly dolomite sequence to the lower part of the Elbrook Dolomite (pl. 1, fig. 2).

◀ **Figure 2.** Correlation of Middle Proterozoic, Cambrian, and Ordovician rocks along section *E–E'* and in adjoining northern Virginia. Absolute age (in Ma) is taken from the geologic time scale compiled by Palmer (1983). The time scale is nonlinear. North American time-stratigraphic units are modified after Ross and others (1982) and Palmer (1983). Stages: BR, Blackriveran; C, Chazyan; E, Edenian; K, Kirkfieldian; M, Maysrillian; R, Rocklandian; Ri, Richmondian; S, Shermanian. Groups: BRG, Black River Group; SPG, St. Paul Group. Formations: LW, Lincolnshire and Ward Cove Limestones; PB, Peery and Benbolt Limestones; WW, Witten Limestone and Wardell Formation.

The Rome Formation between the Central West Virginia arch and the Allegheny structural front is Early(?) and Middle Cambrian in age. This age assignment is based on three lines of evidence in addition to the Middle Cambrian fossils in the Columbia Gas No. 9674–T Mineral Tract drill hole. First, the Waynesboro (Rome) Formation in northern Virginia has been assigned an Early Cambrian age by King (1950) and Rodgers (1956). Second, on the basis of fossils, Butts (1940) concluded that the Rome Formation in central Virginia is Early and Middle Cambrian in age. Third, again on the basis of fossils, Butts (1945) concluded that the Waynesboro Formation in Blair County, Pennsylvania (fig. 1), is Early Cambrian in age.

Evidence presented here suggests that the Rome Formation in section *E–E'* is a transgressive sequence, the age of which ranges from late Early(?) and Middle Cambrian near the Allegheny structural front, to Middle Cambrian in the Rome trough, to latest Middle Cambrian or earliest Late Cambrian at the western margin of the Ohio-West Virginia hinge zone (pl. 1, fig. 2).

Conasauga Group and Elbrook Dolomite (Middle and Upper Cambrian)

A 2,400- to 2,800-ft-thick sequence of gray shale, limestone, dolomite, and an argillaceous siltstone conformity overlies the Rome Formation in the Rome trough segment of section *E–E'* (pl. 1). This sequence correlates in the Rome trough of eastern Kentucky with a shale and limestone sequence that has been identified as the upper part of the Rome Formation by Thomas (1960) and McGuire and Howell (1963), the Conasauga Group by Webb (1980), and the upper part of the Rome by Sutton (1981). Sutton (1981) subdivided the upper part of the Rome into three informal units, which he named, in ascending order, Signal shale, sandy Rome, and Rome limestone.

Another correlative of the 2,400- to 2,800-ft-thick sequence of shale, carbonate, and siltstone in section *E–E'* is a shale and limestone sequence that was penetrated in the Rome trough of southwestern West Virginia by the Columbia Gas No. 9674–T Mineral Tract drill hole (fig. 1). Donaldson and others (1988) assigned this sequence to the Conasauga Group.

I conclude that Webb (1980) and Donaldson and others (1988) have correctly applied the term Conasauga Group, as used in the thrust belt of eastern Tennessee by Rodgers and Kent (1948) and Rodgers (1953), to strata in the Rome trough. Consequently, I use the term Conasauga Group for the 2,400- to 2,800-ft-thick sequence of shale, carbonate, and siltstone in the Rome trough segment of section *E–E′* (pl. 1). Four of the six formations that compose the Conasauga Group in the Thorn Hill section in Grainger County, Tennessee (fig. 1) (Walker, 1985), are recognized in the strata assigned to the Conasauga Group in section *E–E′*. In ascending order, these four formations are the Pumpkin Valley Shale, the Rutledge Limestone, the Rogersville Shale, and the Maryville Limestone (pl. 1, fig. 2).

Minor differences in Conasauga Group stratigraphy, as proposed in this study and by Webb (1980) and Donaldson and others (1988), stem largely from the stratigraphic assignment of the first thick limestone unit above the sandstone and shale sequence of the Rome Formation. For example, Webb (1980) and Donaldson and others (1988) included this limestone unit in the lower part of their Conasauga Group, whereas I assign it to the upper part of the Rome Formation (unnamed limestone member). Consequently, in my study, the base of the Conasauga Group, which I place at the top of the unnamed limestone member of the Rome Formation, is about 300 ft higher stratigraphically than the base of the Conasauga Group of Webb (1980) and Donaldson and others (1988). The Rome-Conasauga contact proposed here is more consistent with outcrop data in eastern Tennessee (Rodgers, 1953; Walker, 1985) and southwestern Virginia (Butts, 1940) than the contact proposed by Webb (1980) and Donaldson and others (1988) is.

The Pumpkin Valley Shale in section *E–E′* consists of a 50- to 100-ft-thick unit of gray shale and siltstone (pl. 1). This unit correlates with (1) a 180-ft-thick shale in the U.S. Signal Oil No. 1 Elkhorn Coal Corporation drill hole in Johnson County, Kentucky (fig. 1), assigned to the Rogersville Shale by Webb (1980) and to the Signal shale unit of the Rome Formation by Sutton (1981) and (2) a 250-ft-thick shale in the Columbia Gas No. 9674–T Mineral Tract drill hole assigned to the Rogersville Shale by Donaldson and others (1988).

The Rutledge Limestone in section *E–E′* ranges from 200 to 300 ft in thickness and consists of micritic limestone and sandstone (pl. 1). This unit correlates with (1) a 950-ft-thick argillaceous, sandy limestone, which was assigned to the lower two-thirds of the Maryville Limestone by Webb (1980) and to the sandy Rome unit of the Rome Formation by Sutton (1981) in the U.S. Signal Oil No. 1 Elkhorn Coal Corporation drill hole and (2) a 1,200 ft-thick limestone, which was assigned to the lower one-quarter of the Maryville Limestone by Donaldson and others (1988) in the Columbia Gas No. 9674–T Mineral Tract drill hole.

The Rogersville Shale in section *E–E′* consists of a 600- to 700-ft-thick sequence of siltstone, shale, and micritic limestone (pl. 1). It correlates with (1) a 600-ft-thick sequence of shale, micritic limestone, and siltstone in the U.S. Signal Oil No. 1 Elkhorn Coal Corporation drill hole assigned to the upper one-third of the Maryville Limestone by Webb (1980) and to the uppermost part of the sandy Rome and the lower one-quarter of the Rome limestone unit of the Rome Formation by Sutton (1981) and (2) a 750-ft-thick sequence of shale, siltstone, and micritic limestone in the Columbia Gas No. 9674–T Mineral Tract drill hole that Donaldson and others (1988) assigned to the lower middle part of the Maryville Limestone.

The Maryville Limestone in section *E–E′* consists of a 1,500- to 1,600-ft-thick carbonate sequence. The lower one-third of the carbonate sequence consists predominantly of limestone designated here as the unnamed limestone member, whereas the upper two-thirds of the sequence consists predominantly of dolomite designated here as the unnamed dolomite member (pl. 1). Several 10- to 20-ft-thick sandstone beds occupy the middle part of the Maryville Limestone. The Maryville Limestone in section *E–E′* correlates with (1) a 1,750-ft-thick sequence of micritic limestone and shale in the U.S. Signal Oil No. 1 Elkhorn Coal Corporation drill hole assigned to the Elbrook Limestone by Webb (1980) and to the upper three-quarters of the Rome limestone unit of the Rome Formation by Sutton (1981) and (2) a 2,500-ft-thick sequence of micritic limestone and shale in the Columbia Gas No. 9674–T Mineral Tract drill hole that Donaldson and others (1988) assigned to the upper one-half of the Maryville Limestone.

The 240- to 380-ft-thick sandstone-dominated sequence that overlies the Maryville Limestone in section *E–E′* correlates with the Nolichucky Shale of the Conasauga Group in the thrust belt of eastern Tennessee (Rodgers and Kent, 1948; Rodgers, 1953; Walker, 1985) and southwestern Virginia (Butts, 1940) and in the Rome trough of eastern Kentucky (Webb, 1980; Sutton, 1981) and of southwestern West Virginia (Donaldson and others, 1988). This sandstone-dominated sequence also correlates with the lower sandy member of the Gatesburg Formation in Pennsylvania (Wilson, 1952; Wagner, 1966, 1976). Because of the abundance of quartzose sandstone, I believe that the lower sandy member of the Gatesburg Formation is a more appropriate name for this sequence than Nolichucky Shale, and the unit is so shown on section *E–E′*. Additional details of the lower sandy member and the remainder of the Gatesburg are discussed in the following section on the Gatesburg Formation.

The unnamed limestone member of the Rome Formation, the Pumpkin Valley Shale, the Rutledge Limestone, the Rogersville Shale, and the unnamed limestone member of the Maryville Limestone probably intertongue westward with sandstone of the Rome Formation (pl. 1). East of the Rome trough in the vicinity of the Central West

Virginia arch, these units, with the exception of the more extensive unnamed limestone member of the Maryville Limestone, probably grade laterally into the adjoining Elbrook Dolomite. The sandstone beds in the middle part of the Maryville Limestone probably merge westward with the sandstone lithofacies of the Rome Formation, and, very likely, the uppermost of these sandstone beds becomes part of the Mount Simon Sandstone west of the Ohio-West Virginia hinge zone (pl. 1). The unnamed dolomite member of the Maryville Limestone in the Rome trough correlates with a 500- to 700-ft-thick dolomite west of the Ohio-West Virginia hinge zone that Janssens (1973) identified as the Rome Formation. East of the Rome trough, the unnamed dolomite member of the Maryville Limestone becomes the upper 900 ft of the Elbrook Dolomite. The total thickness of the Elbrook Dolomite in the vicinity of the Allegheny structural front is about 2,950 ft.

Several assemblages of fossils in the Pumpkin Valley Shale, the Rutledge Limestone, the Rogersville Shale, and the Maryville Limestone indicate a Middle Cambrian age for these formations in the eastern Tennessee and southwestern Virginia outcrop belt (Resser, 1938). The uppermost part of the Maryville Limestone seems to be Late Cambrian (Dresbachian) in age on the basis of fauna reported by Rasetti (1965) from eastern Tennessee and by Derby (1965) from southwestern Virginia. Judging from these fossils, a Middle Cambrian age is assigned to the majority of the Conasauga Group in the Rome trough segment of section *E–E′* and to the correlative lower part of the Elbrook Dolomite between the Central West Virginia arch and the Allegheny structural front (pl. 1, fig. 2). A Late Cambrian (Dresbachian) age is tentatively assigned to the upper 600 to 800 ft of the unnamed dolomite member of the Maryville Limestone, the upper 500 to 600 ft of the Elbrook Dolomite, and most of the Rome Formation of Janssens (1973) (pl. 1, fig. 2).

Gatesburg Formation (Upper Cambrian)

A 1,000- to 1,600-ft-thick sequence of dolomite, sandstone, and subordinate gray shale overlies the Conasauga Group in the ED, EM, and EGL drill holes (pl. 1). Most of the sandstone is concentrated in 100- to 400-ft-thick zones at the base and top of the sequence. The lower of the sandstone-dominated zones was previously described—in the discussion of the Conasauga Group—as a 240- to 380-ft-thick sandstone-dominated sequence that overlies the Maryville Limestone in section *E–E′*. Although the lower sandstone-dominated sequence correlates with the Nolichucky Shale (Butts, 1940; Rodgers, 1953; Webb, 1980; Sutton, 1981; Donaldson and others, 1988), as well as with the lower sandy member of the Gatesburg Formation (Wilson, 1952; Wagner, 1966, 1976), I favor the name lower sandy member of the Gatesburg Formation.

The name Gatesburg Formation is also applied to the dolomite unit that overlies the lower sandy member and to the upper sandstone-dominated zone. The dolomite unit is assigned here to the unnamed middle dolomite member of the Gatesburg Formation (Wagner, 1966), whereas the upper sandstone-dominated zone is assigned to the upper sandy member of the Gatesburg Formation (Wilson, 1952; Wagner, 1966, 1976). The Stacy Dolomite and Ore Hill Limestone Members of the Gatesburg Formation, recognized in Blair County, Pennsylvania (fig. 1), by Butts (1945) and the Mines Dolomite Member, recognized in central and south-central Pennsylvania by Wilson (1952) and Wagner (1966), cannot be identified in section *E–E′*. The unnamed middle dolomite and upper sandy members in section *E–E′* correlate with the Copper Ridge Dolomite and Rose Run Sandstone (Sand), respectively, in the Rome trough of eastern Kentucky (McGuire and Howell, 1963; Sutton, 1981) and southwestern West Virginia (Donaldson and others, 1988).

The Gatesburg Formation is recognized in section *E–E′* as far west as the HNGP drill hole, where it is characterized by an 850-ft-thick sandstone and dolomite sequence having well-defined lower and upper sandy members (pl. 1). Westward into Ohio, the lower sandy member is replaced laterally by a gray shale and dolomite unit, which was assigned to the Conasauga Formation by Janssens (1973) (pl. 1, fig. 2). The upper sandy member continues into Ohio as a well-defined sandstone unit, which was assigned to the Rose Run Sandstone by Janssens (1973) (pl. 1). At the western end of section *E–E′*, the Conasauga Formation is replaced laterally by a unit dominated by sandstone and siltstone and named the Kerbel Formation by Janssens (1973) (pl. 1, fig. 2). The unnamed middle dolomite member of the Gatesburg Formation continues into Ohio as a well-defined dolomite unit that occupies the lower part of the Knox Dolomite of Janssens (1973) (pl. 1, fig. 2). The lower part of the Knox Dolomite contains a widespread silty and sandy dolomite unit named the B zone by Calvert (1964, 1965).

At the eastern end of section *E–E′*, the name Gatesburg Formation is applied to a 1,700-ft-thick dolomite and sandstone sequence that was penetrated in the UFS drill hole (pl. 1). Thin beds of sandstone seem to be clustered in 300- to 400-ft-thick units near the base, middle, and top of the Gatesburg Formation in this drill hole. The sandy units near the base and top of the Gatesburg are tentatively assigned to the lower and upper sandy members, respectively (pl. 1, fig. 2). Perry (1964) and Donaldson (1969) assigned this sequence in the UFS drill hole to the Copper Ridge Dolomite (Formation). Perry (1964) used the name Copper Ridge to emphasize the similarity of this sequence to the correlative Copper Ridge Dolomite in southwestern Virginia (Butts, 1940; Miller and Fuller, 1954), but he also implied that the name Gatesburg Formation was perhaps equally applicable. Approximately 25 mi east of the UFS drill hole, on the eastern side of the North Mountain fault in northern Virginia (fig. 1), the Gatesburg Formation correlates with a 2,500- to 3,000-ft-thick sequence of sandy limestone and dolomite that was identified as the Conococheague Formation (Limestone) (Butts, 1940; King, 1950; Wilson, 1952; Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1976; Rader, 1982) (fig. 2).

Outcrops of the Gatesburg Formation in Blair and Centre Counties, Pennsylvania (fig. 1), were assigned a Late Cambrian (Franconian and Trempealeauan) age by Butts (1945) and Wilson (1951, 1952). This age was determined largely from trilobites found in the middle part of the Gatesburg. Using trilobite faunas, Butts (1945) and Wilson (1951, 1952) also assigned a Late Cambrian age to the Conococheague Formation (Limestone) in adjoining Maryland, West Virginia, and Virginia. Given the age assigned to the Gatesburg and Conococheague Formations in outcrop, the Gatesburg Formation—as identified in section *E–E′* between the Rome trough and the Allegheny structural front—is Late Cambrian in age (pl. 1, fig. 2). A Late Cambrian age for the Gatesburg Formation in section *E–E′* is further supported by the presence of a trilobite fauna of Late Cambrian (Dresbachian) age in the Nolichucky Shale (Resser, 1938; Derby, 1965), a unit in the Conasauga Group of eastern Tennessee and southwestern Virginia that is here considered to be equivalent to the lower sandy member of the Gatesburg. Correlatives of the Gatesburg Formation in eastern Ohio—the Conasauga Formation, the Kerbel Formation, the lower part of the Knox Dolomite, and the Rose Run Sandstone—likewise are here assigned a Late Cambrian age (pl. 1, fig. 2).

The possibility exists, however, that a part or all of the upper sandy member of the Gatesburg Formation and the correlative Rose Run Sandstone may be Early Ordovician in age. For example, McGuire and Howell (1963) assigned an Early Ordovician age to the Rose Run Sandstone in eastern Kentucky. This age is consistent with the Early Ordovician age tentatively assigned by Repetski (1985), on the basis of conodonts, to Rose Run-equivalent sandstone beds in the basal part of Chepultepec Dolomite in the Thorn Hill section. Also, on the basis of conodonts, Orndorff (1988) assigned an Early Ordovician age to the upper 141 ft of the Conococheague Formation (Limestone) (fig. 2) as recognized in northern Virginia by Young and Rader (1974), Rader and Biggs (1976), and Rader (1982). Additional paleontologic studies are required before the position of the Upper Cambrian-Lower Ordovician boundary is firmly established in the central Appalachians.

Beekmantown Group (Lower and Lower Middle Ordovician)

Where section *E–E′* crosses the depositional axis of the Rome trough, as defined by the EM and EGL drill holes, a 1,750- to 2,300-ft-thick predominantly dolomite sequence conformably overlies the upper sandy member of the Gatesburg Formation (pl. 1). West of the Rome trough, astride the adjoining Ohio-West Virginia hinge zone, where the ED and HNGP holes were drilled, the dolomite sequence thins noticeably to approximately 1,100 ft (pl. 1). Three laterally persistent, westward-thinning subdivisions of the dolomite sequence are recognized in the Rome trough and adjoining Ohio-West Virginia hinge zone: (1) a lower dolomite unit, (2) a middle sandstone unit, and (3) an upper anhydritic dolomite unit.

In the HNGP drill hole, the three-part sequence of dolomite and sandstone has been identified as the Beekmantown Group by Prouty and others (1959). Wagner (1966) also correlated it with formations in the Beekmantown Group but did not refer to the name Beekmantown Group. Harris (1959) and Wagner (1966) identified an unconformity (now known as the Knox unconformity) in this sequence of dolomite and sandstone in the HNGP drill hole. The stratigraphic position and extent of the Knox unconformity in section *E–E′* are discussed in the following section.

In northern West Virginia, about 20 mi south of the Pennsylvania-West Virginia State line, Wagner (1966) described a sequence of dolomite, limestone, and anhydrite in the lower 2,500 ft of the Phillips Petroleum No. A–1 Finch drill hole in Marion County, West Virginia (fig. 1). This sequence and an estimated 500 to 600 ft of undrilled strata beneath the drill hole together correlate with the three-part sequence of dolomite and sandstone that overlies the upper sandy member of the Gatesburg Formation in section *E–E′*. The lower 200 ft of the drilled sequence in the Phillips Petroleum No. A–1 Finch drill hole was correlated by Wagner (1966) with the upper part of the Mines Dolomite Member of the Gatesburg Formation that crops out in Blair and Centre Counties, Pennsylvania (Butts, 1945; Wilson, 1952). Wagner (1966) correlated the remaining 2,300 ft of the drilled sequence with formations of the Beekmantown Group but did not use the name Beekmantown Group. In ascending order, these formations are (1) the Larke Dolomite (Formation) and the equivalent Stonehenge Limestone (Formation), the Nittany Dolomite (Formation), and the lower member of the Bellefonte Dolomite (Formation), all of which crop out in Blair and Centre Counties, Pennsylvania (Butts and Moore, 1936; Butts, 1945; Swartz and others, 1955; and Donaldson, 1969), and (2) the Rockdale Run Formation that crops out in Washington County, Maryland (fig. 1), and adjoining West Virginia (Sando, 1957; Donaldson and Page, 1963).

According to Wagner (1966), the unconformity that he and Harris (1959) identified in the HNGP drill hole is located at the base of the Bellefonte Dolomite (Formation). Wagner (1966) correlated this basal Bellefonte unconformity with a tentative unconformity in the middle part of the Nittany Dolomite (Formation) in the Phillips Petroleum No. A–1 Finch drill hole. Wagner's tentative correlation of unconformities implies that the Mines-Larke-lower Nittany interval in the Phillips Petroleum No. A–1 Finch drill hole correlates with the lower dolomite unit in section *E–E′*, whereas the upper Nittany-Bellefonte-Rockdale Run interval in the Phillips Petroleum No. A–1 Finch drill hole correlates with the combined middle sandstone and upper anhydritic dolomite units in section *E–E′*.

Following Prouty and others (1959) and Wagner (1966), I assign the name Beekmantown Group to the three-part sequence of dolomite and sandstone that overlies the Gatesburg Formation in section *E–E′*. Because I cannot correlate the three parts of the Beekmantown in section *E–E′* with formations of the Beekmantown Group of Butts (1945) and Sando (1957), I give them informal names. The lower dolomite unit is called the unnamed dolomite, the middle sandstone unit is called the unnamed sandstone, and the upper anhydritic dolomite unit is called the unnamed anhydritic dolomite (pl. 1, fig. 2).

I cannot identify the characteristic highly cherty Mines Dolomite Member of the Gatesburg Formation of Pennsylvania (Wilson, 1952) in section *E–E′*. The Mines Dolomite Member may be missing here owing to facies change or to southward depositional thinning to a zero edge. That the Mines Dolomite Member was overlooked in section *E–E′* is unlikely, because the Mines Dolomite Member-equivalent interval in the HNGP drill hole contains more or less the same variety and amount of chert as the overlying dolomite interval does (Harris and Flowers, 1956; Prouty and others, 1959).

As identified in section *E–E′*, the Beekmantown Group correlates with a 1,600-ft-thick dolomite sequence that overlies the Copper Ridge Dolomite of Donaldson and others (1988) in the Columbia Gas No. 9674–T Mineral Tract drill hole. Donaldson and others (1988) subdivided this 1,600-ft-thick dolomite sequence into three parts: (1) an 800-ft-thick lower dolomite unit named the Beekmantown, (2) a 100-ft-thick middle sandstone unit named the St. Peter, and (3) a 700-ft-thick upper dolomite and anhydritic dolomite unit assigned to the lower one-third of the Middle Ordovician. In ascending order, the three units in the Columbia Gas No. 9674–T Mineral Tract correlate with the unnamed dolomite, the unnamed sandstone, and the unnamed anhydritic dolomite, respectively, of the Beekmantown Group identified in section *E–E′*.

In the Rome trough of southwestern West Virginia, another sequence that correlates with the Beekmantown Group of section *E–E′* is the 1,900-ft-thick dolomite sequence that overlies the Copper Ridge Dolomite in the Exxon No. 1 McCormick drill hole in Lincoln County, West Virginia (fig. 1). There, Cable and Beardsley (1984) applied the name Beekmantown Group to the lower 800 ft of the sequence, which consists largely of dolomite, and the name lower Chazy Group to the upper 1,100 ft of the sequence, which consists of dolomite, shale, sandstone, and local evaporite. Although absent in the Exxon No. 1 McCormick drill hole, the lower Chazy Group commonly contains in nearby drill holes a basal sandstone that Cable and Beardsley (1984) identified as the St. Peter Sandstone. The Beekmantown Group, the St. Peter Sandstone, and the lower Chazy Group of Cable and Beardsley (1984) correlate with the unnamed dolomite, the unnamed sandstone, and the unnamed anhydritic dolomite, respectively, of the Beekmantown Group identified in section *E–E′*.

West of the Ohio-West Virginia hinge zone, the Beekmantown Group is replaced laterally by two formations (pl. 1). The lower formation, the lateral equivalent of the unnamed dolomite of the Beekmantown Group, is assigned to the upper part of the Knox Dolomite of Janssens (1973), whereas the upper formation, the lateral equivalent of the unnamed sandstone and anhydritic dolomite of the Beekmantown, is assigned to the Wells Creek Formation as it is used in Ohio by Stith (1979), Wickstrom and others (1985), and Wickstrom and Gray (1988). The Wells Creek Formation consists largely of grayish-green shale and dolomite. The combined upper Knox-Wells Creek interval and the equivalent Beekmantown Group form a conspicuous westward-tapering wedge of strata that is about 2,300 ft thick in the Rome trough sector of section *E–E′* and thins to about 40 ft thick at the western end of section *E–E′*. This westward thinning of the Beekmantown Group and equivalent strata resulted from a combination of (1) depositional thinning and (2) truncation beneath the Middle Ordovician Knox unconformity (pl. 1).

The unnamed dolomite of the Beekmantown Group, as defined in the Rome trough segment of section *E–E′*, thickens eastward to about 2,150 ft at the Allegheny structural front (pl. 1), where it occupies the entire Beekmantown interval. Most of the eastward thickening of this dolomite interval occurs at the expense of the overlying unnamed anhydritic dolomite and a 450-ft-thick laterally equivalent limestone that I assign in the HNGPF drill hole to the Row Park Limestone of the St. Paul Group (pl. 1). Perry (1964) and Donaldson (1969) assigned the names Beekmantown Dolomite and Beekmantown Formation, respectively, to the 2,150-ft-thick dolomite unit at the Allegheny front. These two designations were applied to emphasize that the unit lacks the well-defined formations of the Beekmantown Group recognized in Blair County, Pennsylvania, by Butts (1945) or in Washington County, Maryland, by Sando (1957). I choose to use the name Beekmantown Group undivided for these dolomite strata along the Allegheny structural front (pl. 1, fig. 2).

The unnamed anhydritic dolomite of the Beekmantown Group and the laterally equivalent Row Park Limestone thin eastward to a zero edge near the Allegheny structural front by changing facies into the unnamed dolomite and the Beekmantown Group undivided (pl. 1). The unnamed sandstone of the Beekmantown Group probably does not extend east of the Rome trough (pl. 1).

Beekmantown-equivalent carbonate strata, 2,500 to 3,700 ft thick, crop out in northern Virginia between the North Mountain fault and the Blue Ridge (fig. 1). Names applied to these strata include (1) Chepultepec Limestone and Beekmantown Group (Butts, 1940), (2) Beekmantown Dolomite (includes Chepultepec Limestone at base) (King, 1950), (3) Chepultepec Limestone and Beekmantown Formation (Edmundson, 1945; Brent, 1960), (4) Beekmantown Group and the constituent Stonehenge Formation, Rockdale Run Formation, and Pinesburg Station Dolomite (Edmundson and Nunan, 1973; Rader, 1982), (5) Stonehenge and Beekmantown Formations (Young and Rader, 1974), and (6) Stonehenge and Rockdale Run Formations (Rader and Biggs, 1976). The Stonehenge Formation as used by Edmundson and Nunan (1973), Young and Rader (1974), and Rader and Biggs (1976) represents the same stratigraphic interval as the Chepultepec Limestone of earlier investigators in northern Virginia. By applying the terms Stonehenge Formation (Limestone) (fig. 2), Rockdale Run Formation (fig. 2), and Pinesburg Station Dolomite, Edmundson and Nunan (1973), Rader and Biggs (1976), and Rader (1982) have extended the Beekmantown Group terminology into northern Virginia (fig. 2).

An Early Ordovician age was assigned to the Beekmantown Group by Butts (1945), Sando (1957), Spelman (1966), and Lees (1967) where it crops out in Blair and Centre Counties, Pennsylvania, and in Washington County, Md. This age designation was based on (1) the stratigraphic position of the Beekmantown between the Gatesburg and Conococheague Formations of Late Cambrian (Franconian and Trempealeauan) age and limestones of Middle Ordovician (Chazyan) age such as the St. Paul Group and (2) local to common occurrences of probable age-diagnostic gastropods, brachiopods, and trilobites. An Early Ordovician age has also been assigned to the Beekmantown Group in outcrops in northern Virginia between the North Mountain fault and the Blue Ridge (Butts, 1940; King, 1950; Brent, 1960; Rader, 1982) (fig. 2).

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 (Canadian) 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 contains strata ranging from earliest (Whiterockian) to early (Chazyan) Middle Ordovician age.

Without conodont age data, the position of the Lower Ordovician-Middle Ordovician boundary within the Beekmantown Group can only be approximated. In section *E–E′*, I suggest that the boundary coincides with the Knox unconformity (pl. 1) that is discussed in more detail in the next section. Beekmantown strata of earliest Middle Ordovician (Whiterockian) age probably are not present in section *E–E′*, but they are very likely present beneath the Knox unconformity in the Phillips Petroleum No. A–1 Finch drill hole in Marion County, W. Va., about 50 mi north of section *E–E′* (fig. 1).

In eastern Ohio, the Lower Ordovician (Ibexian Series) part of the Beekmantown Group is represented by the upper part of the Knox Dolomite of Janssens (1973), whereas the Middle Ordovician (Whiterockian Series) part of the Beekmantown Group is represented by the Wells Creek Formation (pl. 1). From about midway between the Tatum No. 1 Lee (TL) (no. 4, pl. 1, fig. 1, table 1) and the Lakeshore Pipeline No. 1 Marshall (LM) (no. 5, pl. 1, fig. 1, table 1) drill holes to the western end of section *E–E′*, 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 *E–E′*, 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 Morrow County, Ohio, at the western end of section *E–E′*, the Knox unconformity is locally overlain by a 1- to 2-in-thick very sandy shale at the base of the Wells Creek Formation (Glenwood Formation of the drilling industry) (Ryder, in press). Similar concentrations of quartz sand and sandstone have been reported to overlie the Knox unconformity in other parts of the Appalachian basin (Harris, 1959; Wagner, 1966; Mussman and Read, 1986). In the HNGP drill hole, the unconformity described by Harris (1959) and Wagner (1966) is overlain by a 20-ft-thick quartzose sandstone. Although this unconformity was not identified as the Knox unconformity by Harris (1959) and Wagner (1966), they indicated that it extends throughout a wide region. My correlations between drill holes in Morrow County—where the Knox unconformity is well documented—and the HNGP drill hole confirm the presence of the Knox unconformity directly beneath the 20-ft sandstone unit described by Harris (1959) and Wagner (1966).

The sandstone unit identified by Harris (1959) and Wagner (1966) corresponds to the unnamed sandstone of the Beekmantown Group shown in section *E–E′*. Consequently, I suggest that the Knox unconformity can be confidently traced, on the basis of the overlying sandstone, as far east into the Rome trough as the EGL drill hole. Although difficult to identify in the subsurface without the presence of the overlying unnamed sandstone, the Knox unconformity is interpreted here to continue eastward to the Allegheny structural front, where I tentatively place it about 500 ft below the top of the Beekmantown Group undivided in the UFS drill hole (pl. 1, fig. 2). Farther east, in outcrops in northern Virginia between the North Mountain fault and the Blue Ridge, the Knox unconformity has been identified at the top of the Beekmantown Group by Brent (1960), Young and Rader (1974), and Mussman and Read (1986) (fig. 2).

Conodont studies by Harris and Repetski (1982, 1983) indicated that the Knox unconformity decreases in magnitude from southwestern Virginia to northern Virginia. Their studies showed 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 that is latest Early Ordovician (Canadian) in age. Northward, between Harrisonburg, Va. (fig. 1), and central Pennsylvania, the time span of the Knox unconformity is greatly diminished, as shown in outcrop by limestone of early Middle Ordovician (Chazyan) age resting disconformably on the Beekmantown Group, the uppermost beds of which range in age from earliest Middle Ordovician (early Whiterockian) to early Middle Ordovician (Chazyan).

I consider the Knox unconformity identified at the eastern end of section *E–E′* to separate Beekmantown strata of latest Early Ordovician age from overlying uppermost Beekmantown strata of early Middle Ordovician (Chazyan) age (pl. 1, fig. 2). Consequently, the Knox unconformity there represents a time span of 5 to 10 m.y. Across section *E–E′*, the hiatus represented by the Knox unconformity is greatest in north-central Ohio near the northern end of the Waverly arch. There, the lower part of the Knox Dolomite of Late Cambrian (Trempealeauan) age overlain by the Wells Creek Formation of early Middle Ordovician (early to middle Chazyan) age implies that a time span of as much as 40 m.y. is represented by the Knox unconformity (fig. 2).

St. Paul and Black River Groups (Middle Ordovician)

The unnamed anhydritic dolomite of the Beekmantown Group and the adjoining Wells Creek Formation of Ohio and Row Park Limestone of West Virginia are overlain by a sequence of slightly to moderately argillaceous, commonly fossiliferous, micritic limestone. At the eastern end of section *E–E′*, where the unnamed anhydritic dolomite of the Beekmantown Group and the equivalent Row Park Limestone are absent, the micritic limestone sequence rests directly on the Beekmantown Group undivided. One or more metabentonite beds are located near the top of the sequence. From its maximum thickness of 900 to 1,080 ft in the Rome trough, the micritic limestone sequence thins eastward to 760 ft at the eastern end of section *E–E′* and westward to a thickness of 480 ft at the western end of section *E–E′* (pl. 1). Thinning of this sequence between the Rome trough and the Allegheny structural front is largely the result of eastward stratigraphic downstepping of its contact with an overlying, highly argillaceous micritic limestone. Westward thinning of the micritic limestone sequence between the Ohio-West Virginia hinge zone and the Waverly arch resulted from a combination of depositional thinning and a slight westward stratigraphic rise of its basal contact with the underlying Wells Creek Formation.

The micritic limestone sequence is subdivided here into a lower part that commonly contains thin beds of gray to greenish-gray shale and an upper part that contains considerably fewer and thinner beds of shale. 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 HNGP drill hole westward to the western end of section *E–E′*, the shale beds in the lower unit 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 ED drill hole eastward to the HNGPF drill hole, the shale beds in the lower part of the micritic limestone sequence are medium to dark gray. In the UFS drill hole, the lower and lowermost upper parts of the micritic limestone sequence have been replaced laterally by a 380-ft-thick unit that has few shale beds and numerous beds of light-gray to tan, homogeneous (lithographic) micrite.

Perry (1964) assigned the name Lurich Formation to the 380-ft-thick predominantly very fine grained micrite unit in the UFS drill hole. However, in subsequent outcrop studies near the drill hole, Perry (1971, 1972) identified this unit as the New Market Limestone. The New Market Limestone as identified by Perry (1971, 1972) and the underlying Row Park Limestone as recognized here in the HNGPF drill hole (pl. 1, fig. 2) constitute the St. Paul Group as originally defined in outcrop in Washington County, Md., and adjoining States by Neuman (1951). The New Market Limestone extends east of section *E–E′* and crops out in northern Virginia between the North Mountain fault and the Blue Ridge (Young and Rader, 1974; Rader and Biggs, 1976; Rader, 1982) (fig. 2).

The lower unit of the micritic limestone sequence, consisting of argillaceous micrite, correlates with a lithologically similar, 450-ft-thick sequence in the Phillips Petroleum No. A–1 Finch drill hole (fig. 1) that Wagner (1966) assigned to the St. Paul Group. I concur with Wagner (1966) that the St. Paul Group is an appropriate name for New Market-equivalent rocks in this drill hole, and I have therefore retained it for the correlative lower unit of the micritic limestone sequence in section *E–E′*. However, to emphasize the difference in lithologic character between the lower unit and the equivalent New Market Limestone in the UFS drill hole at the eastern end of section *E–E′*, I informally identify the lower unit as the unnamed argillaceous limestone of the St. Paul Group (pl. 1, fig. 2).

In Ohio, the lower part of the micritic limestone sequence has been identified most commonly as (1) the Chazy Group (Limestone) (Calvert, 1962, 1964; Dolly and Busch, 1972), (2) the Black River Group (lower part) (Stith, 1979; Cable and Beardsley, 1984), and (3) the Black River Limestone (lower part) (De Brosse and Vohwinkel, 1974; Wickstrom and others, 1985; Wickstrom and Gray, 1988). All three are acceptable, but I 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 in West Virginia is assigned to the Black River Group (pl. 1, fig. 2). Use of the name Black River Group here follows the nomenclature proposed by Cardwell and others (1968) for outcrops of the sequence in Pendleton County, W. Va., near the UFS drill hole and by Cable and Beardsley (1984) for correlative strata in the Exxon No. 1 McCormick drill hole in Lincoln County, W. Va. (fig. 1). Moreover, Prouty and others (1959) and Wagner (1966) applied the name Black River Group, and (or) its constituent Hatter and Benner Limestones (Formations), to most of the upper part of the micritic limestone sequence in the HNGP and Phillips Petroleum No. A–1 Finch drill holes. The Hatter and Benner Limestones of the Black River Group are not recognized in section *E–E′*.

The Black River Group that was penetrated in the UFS drill hole contains most of the units recognized in nearby outcrops in Virginia by Read (1980) and Rader (1982). In ascending stratigraphic order, these units are the Lincolnshire Limestone, the Ward Cove Limestone, the Peery and Benbolt Limestones undivided, the Wardell Formation, and the Witten Limestone. The Ward Cove–Peery–Benbolt interval represents the Big Valley Formation identified by Perry (1964) in the UFS drill hole, and the Wardell Formation and Witten Limestone represent the units that he identified as the McGlone and McGraw Limestones, respectively. In the vicinity of Harrisonburg, Va. (fig. 1), the Lincolnshire Limestone and the overlying 750-ft-thick black shale and limestone sequence of the Liberty Hall Formation (Read, 1980; Rader, 1982) are equivalent to the Black River Group (fig. 2). The Ward Cove Limestone (pl. 1) at the eastern end of section *E–E′*, consisting of black shale and dark-gray to black micritic limestone, is a tongue of the Liberty Hall Formation.

The top of the Black River Group at the Allegheny structural front in West Virginia climbs section westward by about 150 ft, at the expense of the overlying highly argillaceous limestone, to a maximum stratigraphic level in the Rome trough segment of section *E–E′* (pl. 1). There, the top of the Black River Group is marked by a metabentonite that I identify as the α marker of Stith (1979) (pl. 1, fig. 2). East of the Rome trough, I identify the metabentonite as the S_2 metabentonite of Perry (1964) (pl. 1, fig. 2). Although Prouty and others (1959) and Wagner (1966) recognized the Black River Group and (or) its constituent formations in the HNGP and Phillips Petroleum No. A–1 Finch drill holes, they placed its top 150 to 200 ft below this metabentonite. Very likely, they did not account for the westward stratigraphic rise of the upper part of the micritic limestone sequence.

Following De Brosse and Vohwinkel (1974), Wickstrom and others (1985), and Wickstrom and Gray (1988), I 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 St. Paul Group in West Virginia (pl. 1, fig. 2). The α marker of Stith (1979) marks the top of the Black River Limestone across the entire Ohio segment of section *E–E′* (pl. 1, fig. 2). Another metabentonite in the uppermost part of the Black River underlies the α marker from the Ohio-West Virginia hinge zone to the western end of section *E–E′*. This metabentonite correlates 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).

A Middle Ordovician (late Chazyan through early Blackriveran) age is assigned here to the Row Park Limestone, the New Market Limestone, and the unnamed argillaceous limestone of the St. Paul Group (fig. 2). This age is based on diverse faunas reported by Neuman (1951) from outcrops of the St. Paul Group in Washington County, Md., and adjoining areas and by Prouty and others (1959) from cores of the Loysburg Limestone (unnamed argillaceous limestone of this paper) in the HNGP drill hole (F_1, pl. 1). The New Market Limestone in Maryland and adjoining States was assigned by Neuman (1951) a Pamelian age, which is equivalent to an early Blackriveran age as defined by Sweet and Bergström (1976).

I assign a Middle Ordovician (Blackriveran through Rocklandian) age to the Black River Group (fig. 2). This age is based on faunas reported by Neuman (1951) from outcrops of the Lincolnshire Limestone in northwestern Virginia; by Kay (1956) from outcrops of the Ward Cove through McGraw (Witten of this paper) Limestones in

Pendleton County, W. Va., and adjoining Virginia (F_3, pl. 1); by Prouty and others (1959) from cores of the Hatter and Benner Limestones of the Black River Group and the lower part of the Nealmont Limestone (included in this paper with the Black River Group) in the HNGP drill hole (F_1, pl. 1); and by Sweet and Bergström (1976) from strata between the α (Mud Cave bentonite) and β (Pencil Cave bentonite) markers in southern Ohio and adjoining Kentucky. The now-abandoned Bolarian Series, to which Kay (1956) assigned the Ward Cove through McGraw Limestones (Formations), is equivalent to the Blackriveran Stage of Sweet and Bergström (1976).

Because the Black River Limestone, as used in Ohio by De Brosse and Vohwinkel (1974) and Wickstrom and others (1985), includes strata equivalent to the upper part of the St. Paul Group, its age ranges from late Chazyan through Rocklandian (fig. 2).

Trenton Group (Middle and Upper Ordovician)

The Black River Group (Limestone) in section *E–E′* is overlain by a westward-thinning sequence consisting of bioclastic limestone, argillaceous micritic limestone, and dark-gray to black shale (pl. 1). This sequence ranges in thickness from 650 ft at the Allegheny structural front to 250 ft near the crest of the Waverly arch. The most abrupt thickening of the sequence occurs between the EGL and the UFS drill holes, where its base steps downsection toward the east at the expense of the underlying Black River Group (pl. 1). Between the EGL drill hole and the UPM drill hole at the western end of section *E–E′*, the limestone and gray to black shale sequence maintains about the same thickness (pl. 1).

The limestone and gray to 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 to black shale and argillaceous micritic limestone (pl. 1). These units are most easily recognized between the HNGP and UPM drill holes, where the lower unit consists of bioclastic limestone and the upper unit consists of black shale. East of the HNGP drill hole, these two units change facies. The eastward facies change in the lower unit is marked by a gradual increase in argillaceous micritic limestone at the expense of bioclastic limestone. In contrast, the eastward facies change in the upper unit is marked by an abrupt increase in argillaceous micritic limestone and medium- to dark-gray shale at the expense of black shale (pl. 1). The lower and upper units are differentiated between the HNGP and UFS drill holes by the significantly higher percentage of shale in the upper unit. Metabentonite beds are common in the lower and upper units of the limestone and gray to black shale sequence (pl. 1).

Cardwell and others (1968) and Perry (1971, 1972) assigned the name Trenton Group to outcrops of the limestone and gray to black shale sequence in Pendleton County, W. Va. Perry (1971, 1972) subdivided these outcrops of the Trenton Group into the Nealmont Limestone and the Dolly Ridge Formation. The Nealmont Limestone and the Dolly Ridge Formation (formerly the Edinburg Formation of Perry (1964)) are also recognized in the UFS drill hole (Perry, 1964, 1972), where they correlate with the lower unit and the upper unit, respectively, of the sequence of limestone and gray to black shale.

Wagner (1966) assigned formations of the Trenton Group, as defined by Kay (1944) in Centre County, Pa., to the sequence of limestone and gray to black shale in the HNGP and LM drill holes. The Nealmont (upper part), Salona, and Coburn Formations (Limestones) of Wagner (1966) constitute the lower unit of this report, whereas the Antes Shale of Wagner (1966) constitutes the upper unit. Prouty and others (1959) also applied Trenton terminology to the limestone and gray to black shale in the HNGP drill hole. The Trenton Limestone and Antes Shale of Prouty and others (1959) correlate with the lower unit and the upper unit, respectively, of this report.

Following Wagner (1966), Cardwell and others (1968), and Perry (1971, 1972), I assign the name Trenton Group to the sequence of limestone and gray to black shale in the West Virginia part of section *E–E′* (pl. 1, fig. 2). Moreover, I recognize the Nealmont Limestone and Dolly Ridge Formation but restrict their usage to the region near the Allegheny structural front (pl. 1, fig. 2). From an area about 15 to 20 mi west of the Allegheny structural front to the westernmost part of the Rome trough, the name Trenton Group is applied to the sequence of limestone and gray to black shale. There, I informally subdivide the Trenton Group into an unnamed limestone and an unnamed argillaceous limestone that correlate with the lower unit and the upper unit, respectively, of the sequence of limestone and gray to black shale (pl. 1, fig. 2). The name Trenton Group is also used in the western part of the Ohio-West Virginia hinge zone, where the HNGP drill hole is located. However, there, the lower unit and the upper unit are identified as the unnamed limestone and the Antes Shale of the Trenton Group, respectively (pl. 1, fig. 2). The lower unit is treated informally here because none of the formations of the Trenton Group, as defined by Kay (1944) and Perry (1971, 1972), can be recognized with confidence. In northern Virginia, between the North Mountain fault and the Blue Ridge, the Trenton Group in section *E–E′* correlates with the lower one-half to two-thirds of the Martinsburg Formation (Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1976; Rader, 1982) (fig. 2).

In the Ohio part of section *E–E′*, I assign the lower part of the sequence of limestone and gray to black shale to the Trenton Limestone, as defined by Calvert (1962, 1964), De Brosse and Vohwinkel (1974), Wickstrom and others

(1985), and Wickstrom and Gray (1988) (pl. 1, fig. 2). Following Fettke (1960) and Calvert (1964), I assign the upper unit in Ohio to the Utica Shale. The Utica Shale as used here in the Pan American No. 1 Windbigler (PAW) (no. 2, pl. 1, fig. 1, table 1) consists of both the Utica Shale and the Cynthiana Formation of Calvert (1964). I prefer the name Utica Shale for the upper unit in the Ohio part of section *E–E′* rather than the name Point Pleasant Formation used by Wickstrom and Gray (1988), because the upper unit commonly contains beds of black shale (pl. 1) (Wallace and Roen, 1989). This characteristic of the upper unit makes it more akin to the Utica Shale of northwestern Pennsylvania and adjoining New York (Wagner, 1966) than to the Point Pleasant Formation of southern Ohio and adjoining Kentucky (Weiss and others, 1965).

I assign a Middle and Late Ordovician (Rocklandian through early Edenian) age to the Trenton Group in West Virginia and the combined Trenton Limestone and Utica Shale in Ohio (pl. 1, fig. 2). This age is based on fossils reported by Prouty and others (1959) from cores of the Trenton Limestone (unnamed limestone of this paper) and the Antes Shale in the HNGP drill hole (F_1, pl. 1); by Kay (1944) and Sweet and Bergström (1976) from outcrops of the Trenton Group in central Pennsylvania; by Kay (1956) from outcrops of the Trentonian Stage in Pendleton County, West Virginia, and adjoining Virginia (F_3, pl. 1); and by Sweet and Bergström (1976) from strata between the α (Mud Cave bentonite) and β (Pencil Cave bentonite) markers that crop out in southern Ohio and adjoining Kentucky.

Trenton Group strata of Rocklandian age in section *E–E′* are located primarily in the lower part of the Nealmont Limestone (below the S_2 metabentonite of Perry (1964)) and laterally equivalent strata of the Trenton Group undifferentiated (pl. 1, fig. 2). These Trenton Group strata of Rocklandian age are replaced through facies change by Black River Group strata of Rocklandian age about 20 to 30 mi west of the HNGPF drill hole (pl. 1). In contrast, Trenton Group strata of Kirkfieldian, Shermanian, and Edenian age are distributed throughout section *E–E′* (fig. 2). A Kirkfieldian through Shermanian age is assigned to the following parts of the Trenton Group and Trenton Limestone: (1) all except the uppermost part of the Nealmont Limestone (from the S_2 metabentonite to near the top), (2) all except the uppermost part of the unnamed limestone of the Trenton Group in the ED and HNGP drill holes, and (3) all except the uppermost part of the Trenton Limestone in Ohio (fig. 2). An Edenian age is assigned to the following parts of the Trenton Group and Limestone: (1) the Dolly Ridge Formation and the uppermost part of the Nealmont Limestone, (2) the Antes Shale and the uppermost part of the unnamed limestone, and (3) the Utica Shale and the uppermost part of the Trenton Limestone in Ohio (fig. 2).

Reedsville Shale and Oswego Sandstone (Upper Ordovician)

The Trenton Group and the combined Trenton Limestone and Utica Shale in section *E–E′* are overlain by a sequence of silty and calcareous gray shale (pl. 1). This sequence gradually thins westward from a thickness of 1,800 ft at the Allegheny structural front to 800 ft near the crest of the Waverly arch. The upper 350 ft of the exposed gray shale sequence in Pendleton County, W. Va., near the UFS drill hole, consists of a very sandy interval that grades upward into a 125-ft-thick argillaceous sandstone (Prouty, 1927; Perry, 1971). The sandy gray shale and the overlying argillaceous sandstone also are present in the HNGPF drill hole, but they pinch out approximately 10 mi west of the drill hole.

The sandy part of the gray shale sequence in the Pendleton County outcrops and in the HNGPF drill hole is underlain by a 1,100-ft-thick silty shale. This silty shale thins to about 600 ft in the EGL drill hole, where its upper part is laterally equivalent to the sandy shale and the argillaceous sandstone (pl. 1). About 15 mi west of the HNGP drill hole, the silty part of the gray shale splits into two silty calcareous gray shale units—a lower silty calcareous gray shale that continues to the western end of section *E–E′* and an upper silty calcareous gray shale that pinches out about 10 mi east of the western end of section *E–E′* (pl. 1). The western part of the upper silty calcareous gray shale is overlain, about 50 ft upsection, by a lithologically similar 50- to 75-ft-thick unit that pinches out eastward and extends westward to the western end of section *E–E′*.

The lower part of the gray shale sequence in the Pendleton County outcrops consists of a 400-ft-thick calcareous shale (pl. 1). Across section *E–E′*, it maintains a relatively uniform thickness ranging from 280 to 540 ft. Most lateral thickness changes in the calcareous shale result from intertonguing between the calcareous shale and the overlying silty shale (pl. 1).

Following Cardwell and others (1968), Perry (1971, 1972), and Rader (1982), the gray shale sequence and the overlying argillaceous sandstone are assigned to the Reedsville Shale and the Oswego Sandstone, respectively. Moreover, following Fettke (1960) and Calvert (1963, 1964), the name Reedsville Shale is applied to the gray shale sequence in western and central West Virginia and eastern Ohio (pl. 1, fig. 2). The Reedsville Formation of Calvert (1964) differs slightly from the Reedsville Shale used in this report. For example, in the PAW drill hole, the Reedsville Formation of Calvert (1964) consists of both the Utica and Reedsville Shales of this report. Wickstrom and Gray (1988) applied the name Cincinnatian Group undifferentiated to strata in Ohio that are referred to here as the Reedsville Shale.

In northern Virginia, between the North Mountain fault and the Blue Ridge, the Reedsville Shale correlates with the upper part of the Martinsburg Formation (Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1976; Rader, 1982; Diecchio, 1985) (fig. 2). The Oswego Sandstone has been removed from this region by pre-Silurian erosion (Rader, 1982; Diecchio, 1985).

The Reedsville Shale and the Oswego Sandstone are assigned a Late Ordovician age. The Reedsville Shale is approximately middle Edenian through Maysvillian age, and the Oswego Sandstone is approximately latest Maysvillian through earliest Richmondian age (fig. 2). These ages are based on fossils reported by Prouty (1927) and Bretsky (1970) (F_2, pl. 1) from outcrops of the Reedsville Shale (Martinsburg Shale of Prouty (1927)) in Pendleton County, W. Va., and adjoining Virginia; by Butts (1945) and Bretsky (1970) from outcrops of the Reedsville Shale in Blair County, Pa.; and by Sweet and Bergström (1976) and Sweet (1979) from Reedsville-equivalent outcrops in southern Ohio and adjoining Kentucky. The conodont-based latest Shermanian through earliest Maysvillian age assigned by Diecchio (1985) and Diecchio and others (1985) to the Reedsville Shale in Pendleton County, W. Va., seems too old, given the data presented in this study.

Juniata Formation and Queenston Shale (Upper Ordovician)

The Reedsville Shale and the Oswego Sandstone in section *E–E′* are overlain by a silty and sandy red shale sequence (pl. 1). Except for a slight increase in thickness in the HNGPF and EGL drill holes, this sequence gradually thins westward from a thickness of 700 ft at the Allegheny structural front to 110 ft near the crest of the Waverly arch. Sandstone beds are most common in the red shale sequence at the eastern end of section *E–E′* in Pendleton County, West Virginia, where Perry (1971) identified a 120-ft-thick argillaceous sandstone in the middle of the sequence (pl. 1). The sandstone beds diminish westward and appear to be absent in the EGL drill hole. Numerous siltstone beds appear in the red shale sequence between Pendleton County, West Virginia, and the LM drill hole (pl. 1). About midway between the TL and the Pan American No. 1 Palmer (PAP) (no. 3, pl. 1, fig. 1, table 1) drill holes, the base of the red shale sequence rises stratigraphically about 100 ft and overlies the silty, calcareous gray shale that marks the top of the Reedsville Shale. The red color of the shale persists west of this stratigraphic rise, but, commonly, gray shale is the dominant lithology.

The name Juniata Formation has been applied to the exposed silty and sandy red shale sequence in Pendleton County, West Virginia, by Cardwell and others (1968) and Perry (1971) and to the silty red shale sequence in the HNGP drill hole by Bayles and others (1956) and Harris (1959). In eastern Ohio, the name Queenston Shale has been applied to the silty red shale sequence by Fettke (1960), Calvert (1964), and De Brosse and Vohwinkel (1974). Following these studies, I assign the name Juniata Formation to the red shale sequence in the West Virginia part of section *E–E′* and the name Queenston Shale to the red shale sequence in the Ohio part of section *E–E′*. In northern Virginia, between the North Mountain fault and the Blue Ridge, the Juniata Formation and equivalent strata have been removed by pre-Lower Silurian erosion (Rader, 1982; Diecchio, 1985) (fig. 2).

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

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

The Juniata Formation is conformably overlain by a 130- to 200-ft-thick quartzose sandstone known as the Lower Silurian Tuscarora Sandstone (Bayles and others, 1956; Cardwell and others, 1968; Perry, 1971; Diecchio, 1985) (pl. 1). In eastern Ohio, the Tuscarora Sandstone interval is occupied by a sequence of sandstone and gray shale known informally as the "Clinton" sands of the drilling industry (Pepper and others, 1953) and the "Clinton" sandstone and shale (Janssens, 1977). Pepper and others (1953) indicated that the "Clinton" sands are equivalent to the Albion Sandstone of western New York (now part of the Medina Group of Fisher (1954)) rather than to the stratigraphically younger Clinton Formation (now the Clinton Group of Fisher (1954)) of western New York. In the western part of section *E–E′*, the "Clinton" sandstone and shale of Janssens (1977) changes facies into a basal argillaceous dolomite sequence called the Brassfield Formation and an overlying sequence of dolomite and green shale called the Cabot Head Formation (Janssens, 1977; Wickstrom and others, 1985) (pl. 1). The "Clinton" sandstone and shale and the adjoining Brassfield-Cabot Head sequence are overlain by a continuous 20- to 50-ft-thick dolomite and limestone unit known as the Packer shell in driller's terminology (Pepper and others, 1953) in eastern Ohio and the Dayton Formation in north-central Ohio (De Brosse and Vohwinkel, 1974; Janssens, 1977; Wickstrom and others, 1985) (pl. 1).

SUMMARY AND CONCLUSIONS

A 310-mi-long restored section between Morrow County, Ohio, and Pendleton County, W. Va., shows a

Cambrian and Ordovician sequence that thickens abruptly eastward across two fault-controlled hinges. The westernmost hinge, identified here as the Ohio-West Virginia hinge zone, separates slightly extended Precambrian basement rocks to the west from greatly extended Precambrian rocks to the east. From west to east, the most prominent structural features in the block-faulted terrane east of the Ohio-West Virginia hinge zone are (1) the Rome trough, (2) the Central West Virginia arch of Kulander and Dean (1978), interpreted here as a horst block, (3) the Eastern West Virginia arch of Kulander and Dean (1978), interpreted here as a horst block, and (4) a major down-to-the-east normal fault (Jacobeen and Kanes, 1975) several miles east of the Allegheny structural front that defines the second hinge zone. The Cambrian and Ordovician sedimentary cover thickens across the Ohio-West Virginia hinge zone from about 2,700 ft in central Ohio to about 11,300 ft in the Rome trough of West Virginia. East of the Rome trough, the sedimentary cover thins across the Central West Virginia arch to an estimated 10,000 ft before reestablishing an eastward-thickening trend marked by an estimated 12,300-ft-thick sequence at the Allegheny structural front and an estimated 14,100-ft-thick sequence east of the second hinge zone.

In general, the Cambrian and Ordovician sequence presented 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 shale unit, and (4) shale and sandstone unit. Each of these units and most associated subunits thicken from west to east across the restored section.

The sandstone, shale, limestone, and dolomite unit is closely associated with the greatly block faulted Proterozoic basement terrane. Abrupt thickness changes in the unit across individual fault blocks indicate that sedimentation was fault controlled. Two distinct subunits constitute the sandstone, shale, limestone, and dolomite unit: (1) an older subunit located between the Central West Virginia arch and the eastern end of the restored section and (2) a younger subunit located largely between the Ohio-West Virginia hinge zone and the Central West Virginia arch.

The older of these subunits is speculative because it has not been drilled. I suggest that it consists, in ascending order, of the Chilhowee Group, a basal sandstone unit (equivalent to the uppermost part of the Chilhowee Group), the Shady Dolomite, and the Rome Formation. Except for the Rome Formation, which is in part Middle Cambrian in age, these stratigraphic units are Early Cambrian in age.

The younger subunit is located primarily in the Rome trough and the adjoining Ohio-West Virginia hinge zone. In ascending order, this subunit consists of the basal sandstone unit, limestone of the Shady Dolomite, the Rome Formation, and the Conasauga Group (Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, and the lower one-half of the Maryville Limestone). Here, the basal sandstone unit and limestone of the Shady Dolomite are probably Early Cambrian in age, whereas the Rome Formation and the Conasauga Group, on the basis of fossils, are probably Middle Cambrian in age. The Shady Dolomite is probably overlain unconformably by the Rome Formation. The Rome Formation in the younger subunit climbs abruptly upsection at the expense of the Conasauga Group and steps westward across progressively higher fault blocks of the Ohio-West Virginia hinge zone. The uppermost sandstone of the Rome Formation extends west of the Ohio-West Virginia hinge zone as a basal Cambrian sandstone known as the Upper Cambrian Mount Simon Sandstone. The unnamed limestone member of the Rome Formation and the overlying Conasauga Group (Middle Cambrian part) of the younger subunit, except for the more extensive unnamed limestone member of the Maryville Limestone, grade eastward into a lower part of the dolomite and sandstone unit that has expanded 2,950 ft downsection at the expense of the younger subunit. This 2,950-ft-thick lower part of the dolomite and sandstone unit is assigned here to the Middle Cambrian part of the Elbrook Dolomite.

The dolomite and sandstone unit forms the core of the Cambrian and Ordovician sequence along the restored section. Near the crest of the Waverly arch, at the western end of the section, this unit occupies about one-third of the total sequence. In contrast, between the Central West Virginia arch and the Allegheny structural front—where the dolomite and sandstone unit thickens eastward by about 2,950 ft at the expense of the younger subunit of the sandstone, shale, limestone, and dolomite unit—it occupies about one-half of the total sequence. The well-known Knox unconformity is located in the upper part of the sequence of dolomite and sandstone.

The post-Middle Cambrian Elbrook Dolomite part of the dolomite and sandstone unit consists of a large westward-tapering wedge that extends across the entire section. From east to west, the lower part of the wedge consists of (1) the Upper Cambrian part of the Elbrook Dolomite, (2) the unnamed dolomite member of the Maryville Limestone (Upper Cambrian) in the Rome trough and the adjoining Ohio-West Virginia hinge zone, and (3) the Rome Formation of Janssens (1973) between the Ohio-West Virginia hinge zone and the Waverly arch. The middle part of the dolomite and sandstone wedge consists of the Gatesburg Formation (Upper Cambrian) and its three members: the lower sandy member, the middle dolomite member, and the upper sandy member. In Ohio, the position of the Gatesburg Formation is occupied by the Kerbel and Conasauga Formations (lower sandy member equivalent), the lower part of the Knox Dolomite of Janssens (1973) (middle dolomite member equivalent), and the Rose Run Sandstone (upper sandy member equivalent). The upper part of the dolomite and sandstone wedge consists of the

Beekmantown Group (Lower and lower Middle Ordovician) and its three informal subdivisions (in ascending order): (1) unnamed dolomite (Ibexian Stage to Chazyan age), (2) unnamed sandstone (Chazyan age), and (3) unnamed anhydritic dolomite (Chazyan age). West of the Ohio-West Virginia hinge zone, the position of the Beekmantown Group is occupied by the upper part of the Knox Dolomite of Janssens (1973) (unnamed dolomite equivalent) and the Wells Creek Formation (unnamed sandstone and unnamed anhydritic dolomite equivalent).

The Knox unconformity, located at the base of the Chazyan part of the Beekmantown Group, extends across the entire section. Between the Ohio-West Virginia hinge zone and the Waverly arch, the Knox unconformity truncated successively older parts of the Knox Dolomite and the associated Rose Run Sandstone. The Middle Ordovician (Chazyan) part of the Beekmantown Group thins east of the Central West Virginia arch and grades into an equivalent limestone unit assigned here to the Row Park Limestone (Middle Ordovician, Chazyan) of the St. Paul Group. At the Allegheny structural front, the Row Park Limestone interval is occupied by the uppermost part (Chazyan) of the Beekmantown Group undivided. The Knox unconformity at the Allegheny structural front is located about 500 ft below the top of the Beekmantown Group undivided, where it probably separates rocks of Canadian and Chazyan ages.

The limestone and shale unit, which increases in thickness eastward from about 750 ft at the Waverly arch to about 1,450 ft at the Allegheny structural front, is the thinnest of the four major lithofacies. Between the Ohio-West Virginia hinge zone and the Allegheny structural front, the limestone and shale unit consists, in ascending order, of the St. Paul, Black River, and Trenton Groups. In Ohio, the St. Paul and Black River Groups combine to form the Black River Limestone. The name Trenton Group is abandoned in Ohio and replaced by the Trenton Limestone and the overlying Utica Shale.

The St. Paul Group near the Allegheny structural front consists, in ascending order, of the Row Park Limestone (Chazyan Stage) and the New Market Limestone (Chazyan and lowermost Blackriveran Stages). The Row Park Limestone grades westward into the unnamed anhydritic dolomite of the Beekmantown Group approximately 20 mi west of the Allegheny structural front, whereas the New Market Limestone grades westward, in large part, into the unnamed argillaceous limestone of the St. Paul Group, an informal unit that extends from about 10 mi west of the Allegheny structural front to the Ohio-West Virginia hinge zone.

The Black River Group is undivided in the section except near the Allegheny structural front, where it consists, in ascending order, of the Lincolnshire Limestone, the Ward Cove Limestone, the Peery and Benbolt Limestones undivided, the Witten Limestone, and the Wardell Formation. There, the Black River Group is nearly all Blackriveran in age. The Black River Group thickens westward of the Allegheny structural front, at the expense of the Trenton Group, to include the α and β (bentonite) markers of Stith (1979) and strata of Rocklandian age. The Black River Limestone of Ohio, which correlates with the Black River and the St. Paul Groups combined, has a Chazyan through Rocklandian age.

The Trenton Group of the Allegheny structural front consists of the Nealmont Limestone (Middle Ordovician, Rocklandian through Shermanian Stages) and the overlying Dolly Ridge Formation (Upper Ordovician, Edenian Stage). Both formations contain metabentonite beds. The S_2 metabentonite of Perry (1964) in the Nealmont Limestone correlates with the α (bentonite) marker of Stith (1979) that marks the top of the Black River Group and Limestone farther west. The lower (Rocklandian Stage) part of the Nealmont Limestone grades westward into the upper part of the Black River Group, and the upper (Kirkfieldian-Shermanian Stages) part of the Nealmont grades westward into the unnamed limestone of the Trenton Group. Lateral equivalents of the Dolly Ridge Formation west of the Rome trough are the Antes Shale (Edenian) of the Trenton Group in West Virginia and the Utica Shale (Edenian) in Ohio.

The wedge-shaped shale and sandstone unit thickens eastward from about 900 ft at the Waverly arch to about 2,900 ft midway between the Central West Virginia arch and the Allegheny structural front and then thins slightly to 2,600 ft at the Allegheny structural front. 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, sandstone, and micritic limestone of the Reedsville Shale (Upper Ordovician, middle Edenian through Maysvillian Stages) extends across the entire section, whereas the argillaceous sandstone of the Oswego Sandstone (Upper Ordovician, upper Maysvillian and lower Richmondian Stages) pinches out westward near the Central West Virginia arch. The Juniata Formation (Upper Ordovician, Richmondian Stage) and its correlative unit in Ohio, the Queenston Shale, extend across the entire section and consist predominantly of red shale, siltstone, and sandstone.

REFERENCES CITED

Ahmad, M.U., and Smith, J.A., 1988, Earthquakes, injection wells, and the Perry nuclear power plant, Cleveland, Ohio: Geology, v. 16, no. 8, p. 739–742.

Bass, M.N., 1959, Basement rocks from the Sandhill well, Wood County, West Virginia, *in* Woodward, H.P., ed., A symposium on the Sandhill deep well, Wood County, West Virginia: West Virginia Geological and Economic Survey Report of Investigations 18, p. 145–158.

———1960, Grenville boundary in Ohio: Journal of Geology, v. 68, p. 673–677.

Bayles, R.E., Henry, W.H., Fettke, C.R., Harris, L.D., Flowers, R.R., and Haught, O.L., 1956, Well log, sample, and core description, *in* Haught, O.L., ed., Wood County deep well: West Virginia Geological and Economical Survey Report of Investigations 14, p. 5–28.

Beardsley, R.W., and Cable, M.S., 1983, Overview of the evolution of the Appalachian basin: Northeastern Geology, v. 5, no. 3/4, p. 137–145.

Brent, W.B., 1960, Geology and mineral resources of Rockingham County: Virginia Division of Mineral Resources Bulletin 76, 174 p., 1 map, scale 1:62,500.

Bretsky, P.W., Jr., 1970, Upper Ordovician ecology of the central Appalachians: Yale University Peabody Museum of Natural History Bulletin 34, 150 p.

Butts, C., 1940, Geology of the Appalachian Valley in Virginia, pt. I: Virginia Geological Survey Bulletin 52, 568 p.

———1945, Hollidaysburg-Huntingdon [quadrangles], Pennsylvania, folio 227 *of* Geologic Atlas of the United States: U.S. Geological Survey, 20 p.

Butts, C., and Moore, E.S., 1936, Geology and mineral resources of the Bellefonte quadrangle, Pennsylvania: U.S. Geological Survey Bulletin 855, 111 p.

Cable, M.S., and Beardsley, R.W., 1984, Structural controls on Late Cambrian and Early Ordovician carbonate sedimentation in eastern Kentucky: American Journal of Science, v. 284, no. 7, p. 797–823.

Calver, J.T., and Hobbs, C.R.B., Jr., 1963, Geologic map of Virginia: Charlottesville, Virginia Division of Mineral Resources, 1 sheet, scale 1:500,000.

Calvert, W.L., 1962, Sub-Trenton rocks from Lee County, Virginia to Fayette County, Ohio: Ohio Division of Geological Survey Report of Investigations 45, 57 p.

———1963, Sub-Trenton rocks of Ohio in cross sections from West Virginia and Pennsylvania to Michigan: Ohio Division of Geological Survey Report of Investigations 49, 5 p.

———1964, Cambrian erosional remnants yield oil in central Ohio: World Oil, v. 158, no. 4, p. 78, 80, 82, 84.

———1965, Cambrian correlations in the Appalachian region, with emphasis on Ohio: Ontario Petroleum Institute annual conference, 4th, Toronto, 1965, Technical Paper 2, v. 4, 11 p.

Cardwell, D.H., 1977, West Virginia gas development in Tuscarora and deeper formations (with structural maps contoured on top of Ordovician and Precambrian): West Virginia Geological and Economic Survey Mineral Resources Series 8, 34 p.

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., compilers, 1968, Geologic map of West Virginia: Morgantown, West Virginia Geological and Economic Survey, 2 sheets, scale 1:250,000.

Cohee, G.V., 1948, Cambrian and Ordovician rocks in Michigan basin and adjoining areas: American Association of Petroleum Geologists Bulletin, v. 32, no. 8, p. 1417–1448.

Cooper, B.N., 1945, Industrial limestones and dolomites in Virginia: Clinch Valley District: Virginia Geological Survey Bulletin 66, 259 p.

Cressman, E.R., and Noger, M.C., 1976, Tidal-flat carbonate environments in the High Bridge Group (Middle Ordovician) of central Kentucky: Kentucky Geological Survey Report of Investigations 18, 15 p.

Cressman, E.R., and Peterson, W.L., 1986, Ordovician System, *in* McDowell, R.C., ed., The geology of Kentucky—A text to accompany the geologic map of Kentucky: U.S. Geological Survey Professional Paper 1151–H, p. H3–H11.

De Brosse, T.A., and Vohwinkel, J.C., compilers, 1974, Oil and gas fields of Ohio: Columbus, Ohio Division of Geological Survey and Ohio Division of Oil and Gas, 1 sheet, scale 1:500,000.

Derby, J.R., 1965, Paleontology and stratigraphy of the Nolichucky Formation in southwest Virginia and northeast Tennessee: Blacksburg, Virginia Polytechnic Institute, unpublished Ph.D. thesis, 468 p.

de Witt, W., Jr. and Milici, R.C., in press, Petroleum geology of the Appalachian basin, *in* Rice, D.D., ed., The geology of North America, Economic geology: Boulder, Colo., Geological Society of America.

Diecchio, R.J., 1985, The Taconic clastic sequence in northern Virginia and West Virginia: Society of Economic Paleontologists and Mineralogists, Eastern Section field trip, Harrisonburg, Va., 1985, Guidebook, 62 p.

Diecchio, R.J., Iverson, B.M., and Hall, J.C., 1985, Conodont age determination of the lower portion of the Taconic clastic sequence at the Allegheny front, Pendleton County, West Virginia [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 88.

Dolly, E.D., and Busch, D.A., 1972, Stratigraphic, structural, and geomorphologic factors controlling oil accumulation in Upper Cambrian strata of central Ohio: American Association of Petroleum Geologists Bulletin, v. 56, no. 12, p. 2335–2369.

Donaldson, A.C., 1969, Stratigraphic framework of stromatolites in Lower Ordovician of the central Appalachians, *in* Donaldson, A.C., ed., Some Appalachian coals and carbonates: Models of ancient shallow-water deposition: Morgantown, West Virginia Geological and Economic Survey [preconvention Geological Society of America field trip, November 1969], p. 357–384.

Donaldson, A.C., and Page, R., 1963, Stratigraphic reference sections of Elbrook and Conococheague Formations (Middle and Upper Cambrian) and Beekmantown Group (Lower Ordovician) in Berkeley and Jefferson Counties, West Virginia: Proceedings of the West Virginia Academy of Sciences, v. 35, p. 159–171.

Donaldson, A.C., Heald, M.T., Renton, J.J., and Warshauer, S.M., 1975, Depositional environment of Rome trough rocks, Mingo County well, West Virginia [abs.]: American Association of Petroleum Geologists Bulletin, v. 59, no. 9, p. 1735.

Donaldson, A.C., Heald,, M., and Warshauer, S., 1988, Cambrian rocks of the Rome trough in West Virginia: Cores from Mingo and Wayne Counties, *in* Smosna, R., organizer, A walk through the Paleozoic of the Appalachian basin, Core workshop presented at the AAPG–ES meeting, Charleston, W. Va., September 13, 1988: Appalachian Geological Society, p. 6–18.

Edmundson, R.S., 1945, Industrial limestones and dolomites in Virginia: Northern and central parts of Shenandoah Valley: Virginia Geological Survey Bulletin 65, 195 p.

Edmundson, R.S., and Nunan, W.E., 1973, Geology of the Berryville, Stephenson, and Boyce quadrangles, Virginia: Virginia Division of Mineral Resources Report of Investigations 34, 112 p., 3 maps, scale 1:24,000.

Fettke, C.R., 1960, Well-sample descriptions in northwestern Pennsylvania and adjacent states: Pennsylvania Geological Survey Bulletin M40, 691 p.

Fisher, D.W., 1954, Stratigraphy of Medinan Group, New York and Ontario: American Association of Petroleum Geologists Bulletin, v. 38, no. 9, p. 1979–1996.

Gates, F.A., and Watson, W.A., 1975, Geological and drilling aspects of Columbia's Mingo County prospect: Society of

Petroleum Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers Paper SPE 5447 [Eastern Region Meeting, Nov. 6–7, 1975], 4 p., 8 figs.

Gathright, T.M., II, and Nystrom, P.G., Jr., 1974, Geology of the Ashby Gap quadrangle, Virginia: Virginia Division of Mineral Resources Report of Investigations 36, 55 p., 1 map, scale 1:24,000.

Gwinn, V.E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge Provinces of the central Appalachians: Geological Society of America Bulletin, v. 75, no. 9, p. 863–900.

Harris, A.G., and Repetski, J.E., 1982, Conodonts revise the Lower-Middle Ordovician boundary and timing of miogeoclinal events in the east-central Appalachian basin [abs.]: Geological Society of America Abstracts with Programs, v. 14, no. 5, p. 261.

———1983, Conodonts document continuous to intermittent deposition across the Lower-Middle Ordovician boundary—Northern Virginia to Bellefont, PA [abs.]: The Virginia Journal of Science, v. 34, no. 3, p. 172.

Harris, L.D., 1959, Ordovician rocks of the Sandhill well in West Virginia, *in* Woodward, H.P., ed., A symposium on the Sandhill deep well, Wood County, West Virginia: West Virginia Geological and Economic Survey Report of Investigations 18, p. 53–68.

———1975, Oil and gas data from the Lower Ordovician and Cambrian rocks in the Appalachian basin: U.S. Geological Survey Miscellaneous Investigations Map I–917–D, 3 sheets, scale 1:2,500,000.

———1978, The eastern interior aulacogen and its relation to Devonian shale-gas production, *in* Second eastern gas shales symposium, v. II: Morgantown, W.Va., U.S. Department of Energy, Morgantown Energy Technology Center, p. 56–72.

Harris, L.D., and Flowers, R.R., 1956, Description of cores, *in* Haught, O.L., ed., Wood County deep well: West Virginia Geological and Economic Survey Report of Investigations 14, p. 34–62.

Harris, L.D., de Witt, W., Jr., and Bayer, K.C., 1982, Interpretive seismic profile along Interstate I–64 from the Valley and Ridge to the coastal plain in central Virginia: U.S. Geological Survey Oil and Gas Investigations Chart OC–123, 1 sheet.

Jacobeen, F., Jr., and Kanes, W.H., 1975, Structure of Broadtop synclinorium, Wills Mountain anticlinorium and Allegheny frontal zone: American Association of Petroleum Geologists Bulletin, v. 59, no. 7, p. 1136–1150.

Janssens, A., 1973, Stratigraphy of the Cambrian and Lower Ordovician rocks in Ohio: Ohio Division of Geological Survey Bulletin 64, 197 p.

———1977, Silurian rocks in the subsurface of northwestern Ohio: Ohio Division of Geological Survey Report of Investigations 100, 96 p.

Kay, G.M., 1944, Middle Ordovician of central Pennsylvania, pt. II, Late Mohawkian (Trenton) Formations: Journal of Geology, v. 52, no. 2, p. 97–116.

Kay, M., 1956, Ordovician limestones in the western anticlines of the Appalachians in West Virginia and Virginia northeast of the New River: Geological Society of America Bulletin, v. 67, no. 1, p. 55–106.

Keith, A., 1903, Cranberry [quadrangle], North Carolina-Tennessee, folio 90 *of* Geologic Atlas of the United States: U.S. Geological Survey, 9 p.

King, E.R., and Zietz, I., 1978, The New York-Alabama lineament: Geophysical evidence for a major crustal break in the basement beneath the Appalachian basin: Geology, v. 6, no. 5, p. 312–318.

King, P.B., 1950, Geology of the Elkton area, Virginia: U.S. Geological Survey Professional Paper 230, 82 p., 6 pls.

Kornfeld, J.A., 1974, Deep West Virginia wildcats seek Cambro-Ordovician gas: World Oil, v. 179, no. 2, p. 55–57.

Kulander, B.R., and Dean, S.L., 1978, Gravity, magnetics and structure, Allegheny Plateau/western Valley and Ridge in West Virginia and adjacent states: West Virginia Geological and Economic Survey Report of Investigation RI–27, 91 p., 3 sheets, scale 1:250,000.

———1986, Structure and tectonics of central and southern Appalachian Valley and Ridge and Plateau provinces, West Virginia and Virginia: American Association of Petroleum Geologists Bulletin, v. 70, no. 11, p. 1674–1684.

Lees, J.A., 1967, Stratigraphy of the Lower Ordovician Axemann Limestone in central Pennsylvania: Pennsylvania Geological Survey Bulletin G52, 79 p.

McGuire, W.H., and Howell, P., 1963, Oil and gas possibilities of the Cambrian and Lower Ordovician in Kentucky: Lexington, Ky., Spindletop Research Center, 216 p.

Miller, R.L., and Fuller, J.O. 1954, Geology and oil resources of the Rose Hill District—The fenster area of the Cumberland overthrust block—Lee County, Virginia: Virginia Geological Survey Bulletin 71, 383 p.

Morris, J.R., 1989, Preventing the pitfalls of seismic: Northeast Oil World, v. 9, no. 11, p. 30, 32.

Mussman, W.J., and Read, J.F., 1986, Sedimentology and development of a passive- to convergent-margin unconformity: Middle Ordovician Knox unconformity, Virginia Appalachians: Geological Society of America Bulletin, v. 97, no. 3, p. 282–295.

Mussman, W.J., Montanez, I.P., and Read, J.F., 1988, Ordovician Knox paleokarst unconformity, Appalachians, *in* James, N.P., and Coquette, P.W., eds., Paleokarst: New York, Springer-Verlag, p. 211–228.

Neuman, R.B., 1951, St. Paul Group: A revision of the "Stones River" Group of Maryland and adjacent states: Geological Society of America Bulletin, v. 62, no. 3, p. 267–324.

Oil and Gas Journal, 1967, Amerada reports Ohio's deepest hole: v. 65, no. 35, p. 156.

———1975, Appalachian drilling coming up dry: v. 73, no. 25, p. 74–75.

———1976, Deep play wanes in Appalachian basin: v. 74, no. 48, p. 32–33.

Orndorff, R.C., 1988, Latest Cambrian and earliest Ordovician conodonts from the Conococheague and Stonehenge Limestones of northwestern Virginia, *in* Sando, W.J., ed., Shorter contributions to paleontology and stratigraphy: U.S. Geological Survey Bulletin 1837–A, p. A1–A18.

Palmer, A.R., compiler, 1983, Decade of North American Geology 1983 time scale: Geology, v. 11, p. 503–504.

Patchen, D.G., Avary, K.L., and Ervin, R.B., coordinators, 1984, Correlation of stratigraphic units in North America, Northern Appalachian region correlation chart: Tulsa, Okla., American Association of Petroleum Geologists, 1 sheet.

Pepper, J.F., de Witt, W., Jr., and Everhart, G.M., 1953, The "Clinton" sands in Canton, Dover, Massillon, and Navarre quadrangles, Ohio: U.S. Geological Survey Bulletin 1003–A, 15 p.

Perry, W.J., Jr., 1964, Geology of Ray Sponaugle well, Pendleton County, West Virginia: American Association of Petroleum Geologists Bulletin, v. 48, no. 5, p. 659–669.

———1971, The structural development of the Nittany anticlinorium in Pendleton County, West Virginia: New Haven, Conn., Yale University, unpublished Ph.D. thesis, 227 p.

———1972, The Trenton Group of Nittany anticlinorium, eastern West Virginia: West Virginia Geological and Economic Survey Circular 13, 30 p.

———1978, The Wills Mountain anticline: A study in complex folding and faulting in eastern West Virginia: West Virginia Geological and Economic Survey Report of Investigations RI–32, 29 p.

Prouty, C.E., Aarons, I.I., McCollough, W.M., Mershon, R.E., and Miller, K.J., 1959, Petrographic, chemical, and faunal studies, Cambro-Ordovician carbonates in the Sandhill well, Wood County, West Virginia, *in* Woodward, H.P., ed., A symposium on the Sandhill deep well, Wood County, West Virginia: West Virginia Geological and Economic Survey Report of Investigations 18, p. 69–97.

Prouty, W.F., 1927, Rocks of Pendleton County below the Clinton, *in* Tilton, J.L., Prouty, W.F., and Price, P.H., Pendleton County: Morgantown, West Virginia Geological Survey, ch. III, 384 p.

Rader, E.K., 1982, Valley and Ridge stratigraphic correlations, Virginia: Virginia Division of Mineral Resources Publication 37, 1 sheet.

Rader, E.K., and Biggs, T.H., 1975, Geology of the Front Royal quadrangle, Virginia: Virginia Division of Mineral Resources Report of Investigations 40, 91 p., 1 map, scale 1:24,000.

———1976, Geology of the Strasburg and Toms Brook quadrangles, Virginia: Virginia Division of Mineral Resources Report of Investigations 45, 104 p., 2 maps, scale 1:24,000.

Rasetti, F., 1965, Paleontology of the Nolichucky Formation in Tennessee: Smithsonian Miscellaneous Collections, v. 148, no. 3, 127 p.

Read, J.F., 1980, Carbonate ramp-to-basin transitions and foreland basin evolution, Middle Ordovician, Virginia Appalachians: American Association of Petroleum Geologists Bulletin, v. 64, no. 10, p. 1575–1612.

———1989, Controls on evolution of Cambrian-Ordovician passive margin, U.S. Appalachians, *in* Crevello, P.D., Wilson, J.L., Sarg, J.F., and Read, J.F., eds., Controls on carbonate platform and basin development: Society of Economic Paleontologists and Mineralogists Special Publication 44, p. 147–165.

Repetski, J.E., 1985, Conodont biostratigraphy of the Knox Group at the Thorn Hill and River Ridge sections, northeastern Tennessee, *in* Walker, K.R., ed., The geologic history of the Thorn Hill Paleozoic section (Cambrian-Mississippian), eastern Tennessee: University of Tennessee Department of Geological Sciences Studies in Geology 10, p. 25–31.

Resser, C.E., 1938, Cambrian System (restricted) of the southern Appalachians: Geological Society of America Special Paper 15, 140 p.

Rodgers, J., 1953, Geologic map of east Tennessee with explanatory text: Tennessee Division of Geology Bulletin 58, pt. 2, 168 p.

———1956, The known Cambrian deposits of the southern and central Appalachian Mountains, *in* El Sistemo Cambrico, Symposium T.2: International Geological Congress, 20th, Mexico City, 1956, v. II, pt. II, Australia, America, p. 353–384.

———1970, The tectonics of the Appalachians: New York, Wiley-Interscience, 271 p.

Rodgers, J., and Kent, D.F., 1948, Stratigraphic section at Lee Valley, Hawkins County, Tennessee: Tennessee Division of Geology Bulletin 55, 47 p.

Ross, R.J., Jr., and others, 1982, The Ordovician System in the United States: International Union of Geological Sciences Publication 12, 73 p.

Ross, R.J., Jr., Bergström, S.M., and Derby, J.R., 1984, Comment on "The Decade of North American Geology 1983 geologic time scale": Geology, v. 12, no. 8, p. 505–506.

Ryder, R.T., 1987, Stratigraphic framework of Cambrian and Ordovician rocks across Rome trough, central Appalachian basin [abs.]: American Association of Petroleum Geologists Bulletin, v. 71, no. 9, p. 1110.

———1988, Depositional setting of Ordovician and Cambrian rocks in central Appalachian basin along a section from Morrow County, Ohio to Calhoun County, West Virginia [abs.]: American Association of Petroleum Geologists Bulletin, v. 72, no. 8, p. 970–971.

———1989, Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin of West Virginia and adjoining states, *in* Programs and abstracts of the 20th Annual Appalachian Petroleum Geology Symposium: West Virginia Geological and Economic Survey Circular C–44, p. 69–73.

———in press, The Knox unconformity and adjoining strata, western Morrow County, Ohio, *in* Shafer, W.E., ed., Morrow County volume: Columbus, Ohio Geological Society.

Sando, W.J., 1957, Beekmantown Group (Lower Ordovician) of Maryland: Geological Society of America Memoir 68, 161 p.

Sanford, B.V., Thompson, F.J., and McFall, G.H., 1985, Plate tectonics—A possible controlling mechanism in the development of hydrocarbon traps in southwestern Ontario: Bulletin of Canadian Petroleum Geology, v. 33, no. 1, p. 52–71.

Shaw, T.H., Roberson, K.E., and Harris, A.G., 1990, Lithostratigraphy and conodont biostratigraphy across the Lower-Middle Ordovician disconformity (early to middle Whiterockian) at Pratt Ferry, central Alabama: U.S. Geological Survey Bulletin 1895–C, p. C1–C19.

Shumaker, R.C., 1986, The effect of basement structure on sedimentation and detached structural trends within the Appalachian basin, *in* McDowell, R.C., and Glover, L., III, eds., The Lowry volume: Studies in Appalachian geology: Virginia Polytechnic Institute, Department of Geological Sciences Memoir 3, p. 67–81.

Shumaker, R.C., Wilson, T.H., Dunne, W.M., Knotts, J., and Buckley, R., 1985, Pennsylvania, Virginia and West Virginia sections, *in* Woodward, N.B., ed., Valley and Ridge thrust belt: Balanced structural sections, Pennsylvania to Alabama: University of Tennessee Studies in Geology 12, ch. I, p. 6–35.

Spelman, A.R., 1966, Stratigraphy of Lower Ordovician Nittany Dolomite in central Pennsylvania: Pennsylvania Geological Survey Bulletin G47, 187 p.

Stith, D.A., 1979, Chemical composition, stratigraphy, and depositional environments of the Black River Group (Middle Ordovician), southwestern Ohio: Ohio Division of Geological Survey Report of Investigations 113, 36 p.

Stose, G.W., 1906, The sedimentary rocks of South Mountain, Pennsylvania: Journal of Geology, v. 14, p. 201–220.

Sutton, E.M., 1981, Deep exploration in eastern Kentucky by the SCLAW group during the early seventies, *in* Proceedings of the technical session, Kentucky Oil and Gas Association, 38th Annual meeting (June 6–7, 1974): Kentucky Geological Survey Special Publication 3, ser. XI, p. 31–44.

Swartz, F.M., Rones, M., Donaldson, A.C., and Hea, J.P., 1955, Stratigraphy of Ordovician limestones and dolomites of Nittany Valley in area from Bellefonte to Pleasant Gap, Pennsylvania: Field Conference of Pennsylvania Geologists, 21st, University Park, Pa., 1955, Guidebook, p. F1–F25.

Sweet, W.C., 1979, Conodonts and conodont biostratigraphy of post-Tyrone Ordovician rocks of the Cincinnati region, *in* Pojeta, J., Jr., ed., Contributions to the Ordovician paleontology of Kentucky and nearby States: U.S. Geological Survey Professional Paper 1066–G, p. G1–G26.

Sweet, W.C., and Bergström, S.M., 1976, Conodont biostratigraphy of the Middle and Upper Ordovician of the United States midcontinent, *in* Bassett, M.G., ed., The Ordovician System: Paleontological Association Symposium, Birmingham, England, 1974, Proceedings: Cardiff, University of Wales Press and National Museum of Wales, p. 121–151.

———1986, Conodonts and biostratigraphic correlation: Annual Review of Earth and Planetary Sciences, v. 14, p. 85–112.

Swingle, G.D., Miller, R.A., Luther, E.T., Hardeman, W.D., Fullerton, D.S., Sykes, C.R., and Garman, R.K., compilers, 1966, Geologic map of Tennessee, east-central sheet: Tennessee Division of Geology, 1 sheet, scale 1:250,000.

Thomas, G.R., 1960, Geology of recent deep drilling in eastern Kentucky, *in* Proceedings of the technical session, Kentucky Oil and Gas Association, 24th Annual Meeting, June 3, 1960: Kentucky Geological Survey Special Publication 3, ser. X, p. 10–28.

Wagner, W.R., 1966, Stratigraphy of the Cambrian to Middle Ordovician rocks of central and western Pennsylvania: Pennsylvania Geological Survey Bulletin G49, 156 p.

———1976, Growth faults in Cambrian and Lower Ordovician rocks of western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 60, no. 3, p. 414–427.

Walker, K.R., ed., 1985, The geologic history of the Thorn Hill Paleozoic section (Cambrian-Mississippian), eastern Tennessee: University of Tennessee Department of Geological Sciences Studies in Geology 10, 128 p.

Wallace, L.G., and de Witt, W., Jr., 1975, Maps showing selected deep wells drilled for oil and gas in the Appalachian basin: U.S. Geological Survey Miscellaneous Investigations Map I–936, 3 sheets, scale 1:1,000,000.

Wallace, L.G., and Roen, J.B., 1989, Petroleum source rock potential of the Upper Ordovician black shale sequence, northern Appalachian basin: U.S. Geological Survey Open-File Report 89–488, 66 p., 7 pls.

Webb, E.J., 1980, Cambrian sedimentation and structural evolution of the Rome trough in Kentucky: Cincinnati, Ohio, University of Cincinnati, unpublished Ph.D. thesis, 98 p.

Weiss, M.P., Edwards, W.R., Norman, C.E., and Sharp, E.R., 1965, The American Upper Ordovician standard, pt. VII, Stratigraphy and petrology of the Cynthiana and Eden Formations of the Ohio Valley: Geological Society of America Special Paper 81, 76 p.

Wickstrom, L.H., and Gray, J.D., 1988, Geology of the Trenton Limestone in northwestern Ohio, *in* Keith, B.D., ed., The Trenton Group (Upper Ordovician Series) of eastern North America: Deposition, diagenesis, and petroleum: American Association of Petroleum Geologists Studies in Geology Series 29, p. 159–172.

Wickstrom, L.H., Botoman, G., and Stith, D.A., 1985, Report on a continuously cored hole drilled into the Precambrian in Seneca County, northwestern Ohio: Ohio Division of Geological Survey Information Circular 51, 1 sheet.

Wilson, J.L., 1951, Franconian trilobites of the central Appalachians: Journal of Paleontology, v. 25, p. 617–654.

———1952, Upper Cambrian stratigraphy in the central Appalachians: Geological Society of America Bulletin, v. 63, no. 3, p. 275–322.

Woodward, H.P., 1961, Preliminary subsurface study of southeastern Appalachian Interior Plateau: American Association of Petroleum Geologists Bulletin, v. 45, no. 10, p. 1634–1655.

Young, R.S., and Rader, E.K., 1974, Geology of the Woodstock, Wolf Gap, Conicville, and Edinburg quadrangles, Virginia: Virginia Division of Mineral Resources Report of Investigations 35, 69 p., 4 maps, scale 1:24,000.

Chapter H

Depositional Environment of the Fincastle Conglomerate near Roanoke, Virginia

By CHRYSA M. CULLATHER

A description of the depositional setting of the synorogenic Ordovician Fincastle Conglomerate found in the eastern overthrust belt of Virginia

U.S. GEOLOGICAL SURVEY BULLETIN 1839

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

CONTENTS

FIGURES

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Depositional Environment of the Fincastle Conglomerate near Roanoke, Virginia

By Chrysa M. Cullather[1]

Abstract

The Fincastle Conglomerate (as used by M.J. Bartholomew and his coworkers in 1982) is the northeasternmost of six Middle Ordovician conglomerates located west of the Blue Ridge structural front in the southern Appalachian Mountains. These conglomerates and their associated sands and shales are an important record of the early tectonic history of the Blue Ridge and the Appalachian basin. They are interpreted as a clastic wedge derived from a southeastern source area. The Fincastle Conglomerate is distinct from the other Middle Ordovician conglomerates because it consists dominantly of terrigenous clasts.

The Fincastle Conglomerate is restricted to the overturned Pine Hills syncline, located 0.96 km north of the town of Fincastle, Va. The syncline trends N. 30° E. for about 3 km and is truncated to the southwest by the Salem fault. The total exposed thickness ranges from 15 to 50 m. Shales, siltstones, and litharenites are discontinuously interbedded with granule to boulder conglomerates. The conglomeratic zones range in thickness from 0.30 to 4.09 m. The grains of the litharenites and the clasts of the conglomerates are thought to have been derived from the Lower Cambrian Chilhowee Group, Cambrian and Ordovician limestones, and sediments from within the basin of deposition.

Eight facies units can be recognized: matrix-supported granule to boulder conglomerate and coarse-grained pebbly sandstone (facies A); clast-supported granule to boulder conglomerate (facies B): fine- to medium-grained sandstones (facies C); laminated to bedded siltstone (facies D); massive and finely laminated shale (facies E); discontinuously interbedded conglomerate, coarse-grained sandstone, and shale (facies F); interbedded shale and sandstone (facies G); and convolute bedded shale (facies H). These units are interpreted as having been deposited by submarine gravity flows. Sedimentary structures include normal and reverse grading, convolute bedding, load casts, loaded flute marks, and intraformational shale clasts. Cross-lamination, ripple marks, and imbrication are very rare. The dominant depositional processes thought to be responsible for the facies of the Fincastle Conglomerate are classified as mass sediment movement. The processes interpreted as being active during the Middle Ordovician include debris flows, high-, medium-, and low-density turbidity currents, grain flows, liquefied and fluidized flows, slumping, and rockfalls. The nature of these lithofacies, the sedimentary structures, and the implied depositional mechanisms indicate that the Fincastle Conglomerate was deposited from an eastern source in a submarine channel at the base of a Middle Ordovician paleoslope.

INTRODUCTION

The Fincastle Conglomerate is the northeasternmost of several Middle Ordovician conglomerates located west of the Blue Ridge structural front in the southern Appalachian Mountains (fig. 1). These conglomerates, six of which were studied by Kellberg and Grant (1956), and their associated sands and shales are an important record of the early tectonic history of the Blue Ridge and the Appalachian basin. Kellberg and Grant (1956) reported that the six conglomerates share several characteristics: (1) lenticular shape, (2) limited areal extent, (3) generally poor sorting, (4) a similar degree of rounding of the clasts, and (5) similarity of lithology, with the exception of the Fincastle. The conglomerates were apparently derived from a southeastern source area (Kellberg and Grant, 1956). The possible source lithologies of the clasts indicare that this source area had a structural relief of between 3,048 and 4,572 m (Tillman and Lowry, 1971; Lowry and others, 1972).

Clasts of the conglomerates in Tennessee and Georgia are dominantly carbonate (78–90 percent), and their matri-

Manuscript approved for publication July 30, 1990.

[1] The Marasco Newton Group, Arlington, VA 22209.

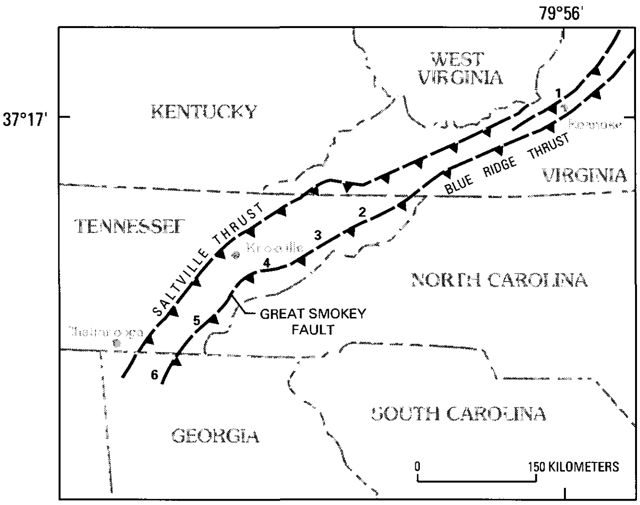

Figure 1. Middle Ordovician conglomerates of the southern Appalachian Mountains. Dashed lines indicate approximate locations of major thrust faults (sawteeth indicate upthrown sides). Numbers indicate locations of Kellberg and Grant's (1956) Middle Ordovician conglomerates: 1, Fincastle, Va.; 2, South Holston Reservoir, Tenn.; 3, Greenville, Tenn.; 4, Douglas Reservoir, Tenn.; 5, Etowah, Tenn.; 6, Cisco, Ga.

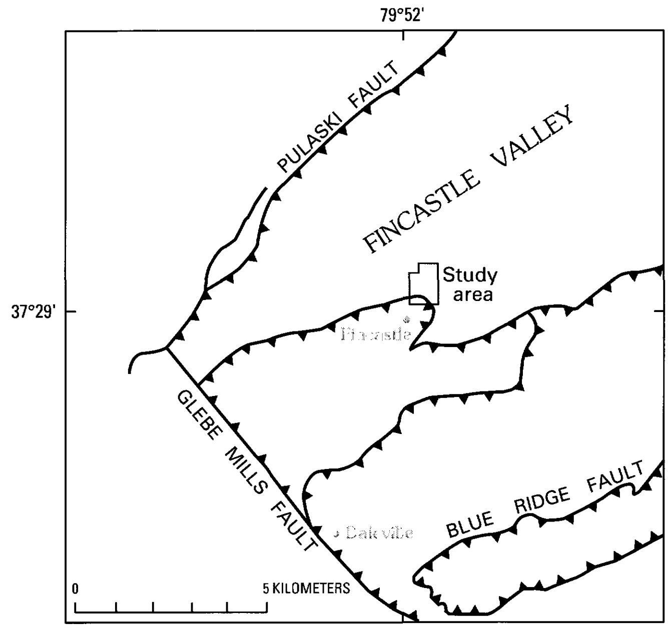

Figure 2. Simplified structural geology of the Fincastle-Roanoke area of Virginia (sawteeth designate upthrown sides of thrust faults) (modified from Bartholomew and others, 1982).

ces are calcareous shales and slightly calcareous sandstones. The Fincastle is more terrigenous in nature. Of the 2,127 clasts measured by Kellberg and Grant (1956, p. 700), only 9 and 38 percent (in fine- and coarse-grained conglomerates, respectively) were composed of carbonate. The remaining clasts were primarily quartzite (9 and 29 percent), vein quartz (22 and 63 percent), and chert (3 and 17 percent). The clasts are assumed to have been derived from Cambrian-Ordovician carbonates, quartzites and other metasediments of the Lower Cambrian Chilhowee Group and basement rocks of the Blue Ridge (Andrews, 1952; Kellberg and Grant, 1956; Cooper, 1960; McGuire, 1970; Lowry and others, 1972; Tillman and Lowry, 1971, 1973; Lowry, 1974; Karpa, 1974).

Acknowledgments

Funding for the fieldwork of this project was provided by the U.S. Geological Survey's Evolution of Sedimentary Basins Program and the George Washington University Geology Department Educational Research Fund. Roy C. Lindholm (George Washington University) suggested appropriate methods of facies analysis. Arthur P. Schultz (U.S. Geological Survey) suggested the research problem and provided guidance on the stratigraphy and structure of the central Appalachian Mountains. Dixon Contracting of Fincastle, Va., was very helpful in allowing access to the quarry where the Fincastle Conglomerate is exposed.

GEOLOGIC SETTING

The Fincastle Conglomerate occurs within the complexly thrust-faulted Valley and Ridge province of the southern Appalachian Mountains. The structure of the Fincastle-Roanoke area of Virginia consists of four main thrusts (from east to west): the Blue Ridge, the Max Meadows, the Salem, and the Pulaski (McGuire, 1970; Amato, 1974; Karpa, 1974; Bartholomew and others, 1982). The multilevel Blue Ridge fault thrusts Cambrian rocks (Chilhowee Group to Rome Formation) to the northwest over the Max Meadows thrust sheet (Amato, 1974; Bartholomew and others, 1982). The Max Meadows thrust sheet is composed mainly of the Cambrian shales of the Rome Formation (McGuire, 1970; Amato, 1974; Karpa, 1974) and overlies the Salem thrust sheet, which is composed mostly of Cambrian and Lower Ordovician carbonates (Elbrook Limestone and Knox Group) (Nichol, 1959; McGuire, 1970; Amato, 1974; Karpa, 1974). The Pine Hills syncline is located within the Pulaski thrust sheet, which, in the study area, is composed dominantly of Middle Cambrian Elbrook Limestone to Middle Ordovician Paperville Shale of Cooper (1956) (Liberty Hall Formation of Campbell (1905)) and Martinsburg Shale. The location of the study area is shown in figure 2. Karpa (1974) estimated the minimum horizontal displacement from the crest of the Blue Ridge anticlinorium to the trough of the Pine Hills syncline to be 49.9 km. The present displacement is approximately 13 km. The present distribution of the

SYSTEM	GROUP	FORMATION	
ORDOVICIAN		Martinsburg Shale	*Fincastle Member*
		Bays Formation	
		Liberty Hall Formation	Paperville Shale
		Botetourt Limestone	
		Lincolnshire Limestone	
		Newmarket Limestone	
		UNCONFORMITY	
	KNOX	Beekmantown Dolomite	
		Stonehenge Limestone	
CAMBRIAN		Conococheague Limestone	Copper Ridge Dolomite
		Elbrook Limestone	
		Rome Formation	
		Shady Dolomite	
	CHILHOWEE	Erwin Formation	
		Hampton Formation	
		Unicoi Formation	
		UNCONFORMITY	
PRECAMBRIAN		Marshall Metagranite	

Figure 3. Stratigraphy of the Fincastle-Roanoke area of Virginia (Cooper, 1960; Karpa, 1974; Read, 1980).

stratigraphic units in the Fincastle-Roanoke area (fig. 3) is very complex owing to folding and faulting. Many facies changes take place along strike, and inconsistencies occur in naming formations. The various formation names used for the local stratigraphy of the Pine Hills area between 1937 and 1989 are summarized in table 1.

The Fincastle Conglomerate is restricted to the overturned Pine Hills syncline (fig. 4), located approximately 1 km north of the town of Fincastle, in Botetourt County, Virginia. The unit trends N. 30° E. for about 3 km and is truncated to the southwest by the Salem fault, a splay of the Pulaski fault (Nichol, 1959; McGuire, 1970; Karpa, 1974). This thrust fault places Cambrian-Ordovician carbonates over the Middle Ordovician strata of the Pine Hills area.

The Fincastle is well exposed on the limbs of the fold in two roadcuts along U.S. Route 220 (fig. 4, section 3). Much of the work on this unit was completed before the most recent roadcuts were made in 1974 and before a new quarry was opened in 1982 (Stow and Bierer, 1937; Butts, 1940; Decker, 1952; Andrews, 1952; Nichol, 1959; Cooper, 1960; McGuire, 1970; Tillman and Lowry, 1971; Karpa, 1974). Dixon Quarry offers the most complete stratigraphic section (fig. 4, section 1) . The Fincastle is also exposed at the nose of the syncline along Catawba Creek (fig. 4, section 2).

PURPOSE AND METHODS

The purpose of this study was to document the facies present in the Fincastle Conglomerate, to determine possible depositional processes for each facies, and to suggest a probable environment of deposition. The fieldwork consisted mainly of compiling detailed descriptions of three stratigraphic sections detailed below. Eleven thin sections were made from six sandstone samples and three conglomerate matrices taken from the quarry section (fig. 4, section 1). Approximately 100 grains per slide were point counted for lithology and grain size.

RESULTS

Reconnaissance field observations showed the conglomerate body to be exposed only within the overturned Pine Hills syncline, as previous workers had reported (Andrews, 1952; Nichol, 1959; McGuire, 1970; Tillman

Table 1. Formation names used between 1937 and 1989 for the Middle Ordovician units of the Pine Hills syncline

[The Fincastle Conglomerate has been regionally coordinated with the Moccasin Formation (Stow and Bierer, 1937; Butts, 1940), the Bays Formation (Decker, 1952; Andrews, 1952; Nichol, 1959; Cooper, 1960; Tillman and Lowry, 1971, 1973; Lowry and others, 1972; Karpa, 1974), and the Eggleston Formation (McGuire, 1970)]

Stow and Bierer (1937), Butts (1940), and Decker (1952)	Nichol (1959)	Cooper (1960)	Kellberg and Grant (1956)	McGuire (1970)	Tillman and Lowry (1971, 1973) and Lowry and others (1972)	Karpa (1974)	Bartholomew and others (1982)	Rader and Gathright (1986), Cullather (1988), and this report
Athens	Martinsburg Formation	Liberty	Tellico Sandstone	Edinburg	Liberty	Martinsburg Formation	Martinsburg Formation	Martinsburg Formation
Fincastle Conglomerate	Fincastle Conglomerate	Fincastle Conglomerate	Fincastle Conglomerate	Fincastle Conglomerate	Fincastle Conglomerate Member	Bays Formation (Fincastle Facies)	Fincastle Conglomerate	Fincastle Conglomerate Member
Formation	Athens Formation	Hall Formation	Athens Shale	Formation	Hall Formation	Liberty Hall Formation (Athens Formation)	Paperville Shale (Liberty Hall Formation)	Paperville Shale

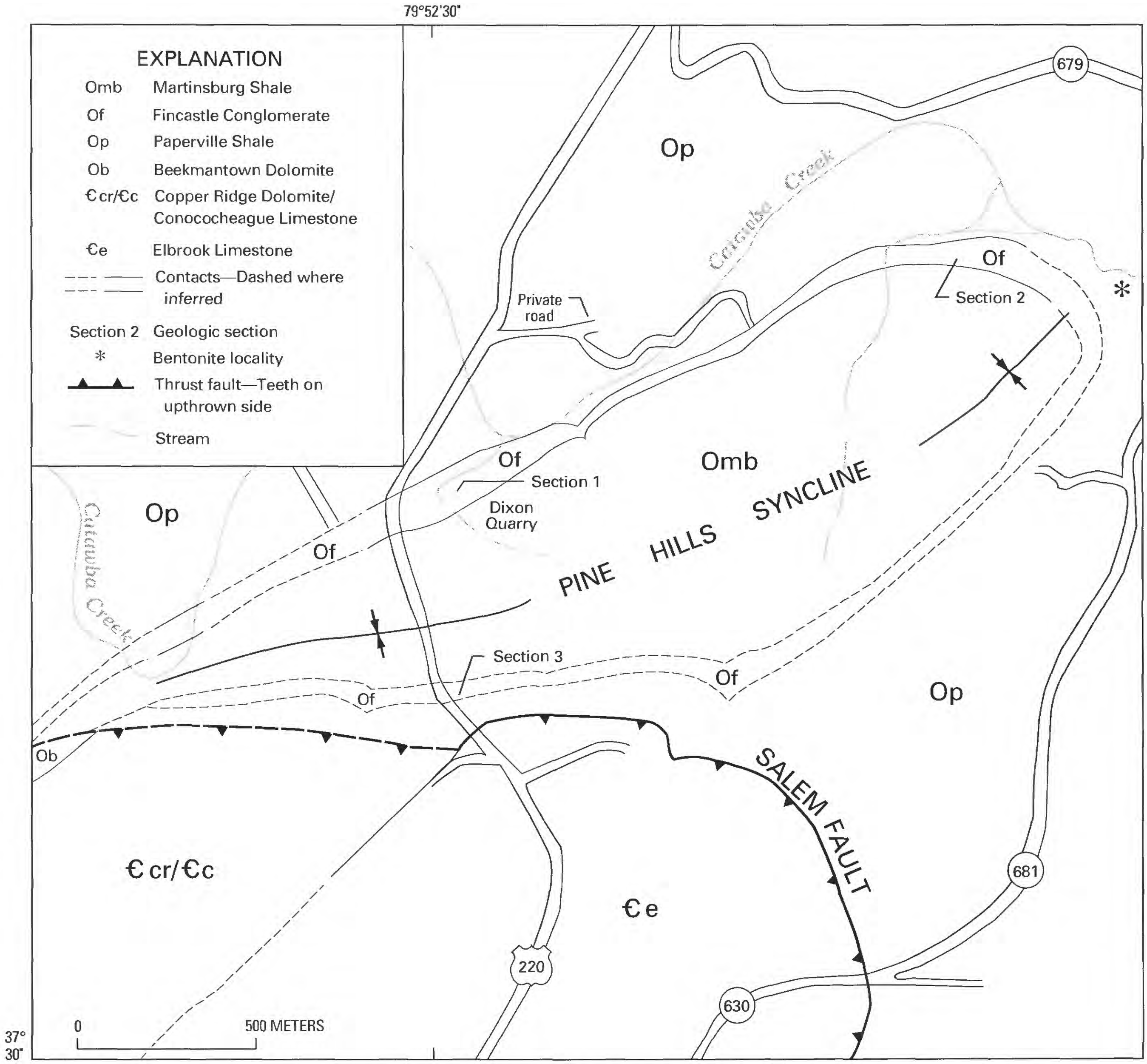

Figure 4. Geology of the Pine Hills area of Virginia (modified from Nichol, 1959; McGuire, 1970; Karpa, 1974).

and Lowry, 1971; Karpa, 1974; Bartholomew and others, 1982). The best exposures are found in the roadcuts along U.S. Route 220, in Dixon Quarry, and along Catawba Creek (fig. 4). Elsewhere, the Fincastle crops out in very small exposures or is found as float. Across U.S. Route 220 to the southwest of the Pine Hills in the bed of Catawba Creek, Middle Ordovician limestones overlie the Fincastle as it thins laterally between the Paperville Shale and the Martinsburg Shale. In the nose of the syncline, Karpa (1974) has shown a considerable thickness of the conglomerate body in the axial portion of the syncline. However, reconnaissance fieldwork showed evidence of numerous small folds and minor faults that may account for the thickening. The three measured sections are given in detail in appendix A.

The Fincastle Conglomerate consists of interbedded gray shales, gray siltstones, gray to brown fine- to medium-grained litharenites, and gray to brown granule to boulder conglomerates. The conglomeratic zones range in thickness from 30 to 409 cm. Much of the bedding is discontinuous, and units cannot be correlated from outcrop to outcrop. The total exposed thickness ranges from 15 to 50 m.

The shales are massive, laminated, or convoluted. The litharenites are most commonly massive but locally

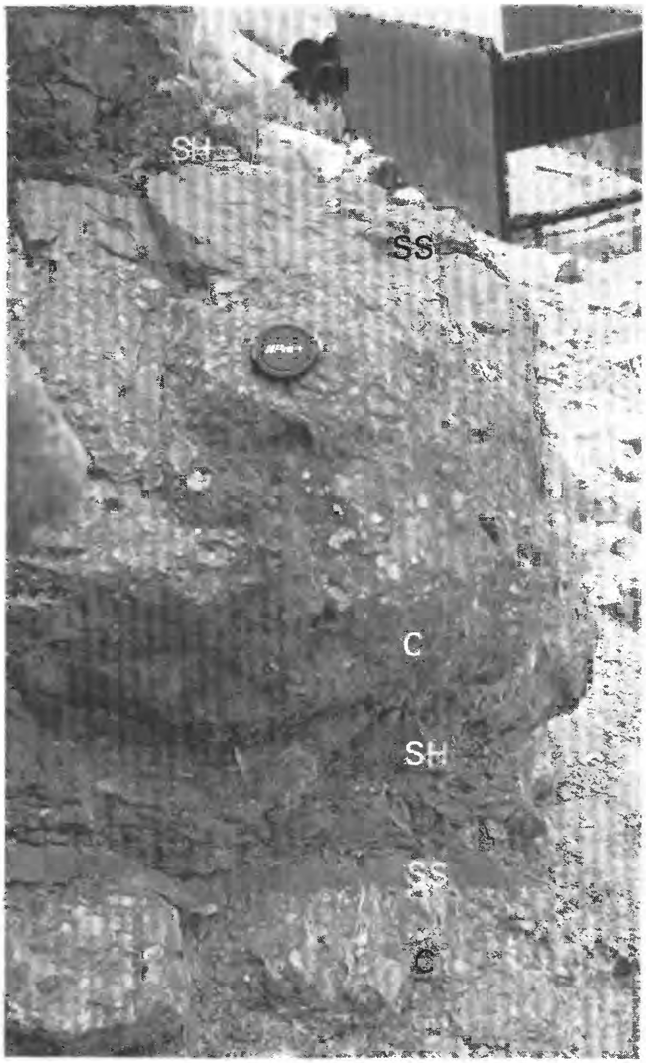

Figure 5. Conglomerate-sandstone-shale cycles. Two small-scale cycles show progression from conglomerate (C) to sandstone (SS) to shale (SH). Taken in the upper portion of the Fincastle Conglomerate in Dixon Quarry. Lens cap is 53 mm in diameter.

show indistinct cross-laminations, ripples, or sole marks. Sole marks are generally load casts formed by the instability of a sand layer deposited on a less dense mud layer. Some flute casts are present but are invariably overprinted by load casts. The siltstones are generally laminated. Several types of conglomerates are present. Matrix-supported conglomerates are pebbly mudstones or pebbly sandstones. Grain-supported conglomerates most commonly have a sandy matrix similar in composition to the litharenites. Some of the grain-supported conglomerates have a muddy matrix similar to the shales. The conglomerates do not show cross-stratification, and only rarely does a conglomerate body contain discrete beds. Imbrication is also rare and, where present, is difficult to measure, as few clasts stand out in relief. Intraformational shale clasts are present in all of the lithologies and range in size from several centimeters to more than 1 m in length. Most are oriented parallel to the bedding surfaces, but some are oblique or contorted and folded.

The grain-size measurements for measured geologic section 1 are given in appendix B. Several grain-size trends are evident from these data. Individual conglomerate units fine upward, coarsen upward, or show reverse grading at the base and change to normal grading at the top. Several of the conglomerate beds contain clasts that are randomly oriented and disorganized. The overall trend is a fining upward of the grain size and a thinning upward of the bed thickness. Cycles show interbedded conglomerates and sandstones, fining and thinning upward, capped by a shale unit (fig. 5) (see also Bartholomew and others, 1982, p. 140.) Several fining-upward trends among the conglomerates can be defined: beds 3 to 9, 18 to 27, 28 to 33, and 35 to 43 (appendix B). Only two coarsening-upward cycles were noted: beds 2 to 3 and 15 to 18. Most of the mean clast sizes range from approximately 30 to 40 mm. The consistency of these values implies that the source of the gravel was moderately well sorted before resedimentation. Additional size sorting probably occurred during secondary flow. Unusually coarse gravel (bed 28) may result from a flow carrying a coarse lag left from previous flows. There is no apparent correlation between the largest gravel clast size and bed thickness.

The observed vertical changes in major clast lithology are shown in figure 6. The amounts of quartz, shale, sandstone, quartzite, and limestone are extremely variable and do not demonstrate any obvious vertical trends. There does appear to be a distribution of gravel clast type by conglomerate type (facies A and B, p. H9). Facies A (matrix-supported conglomerate) tends to contain more limestone clasts than facies B (clast-supported conglomerate) (generally 20–60 percent in comparison with 0–14 percent). Facies B tends to contain more shale clasts than facies A (10–57 percent in comparison with 0–28 percent). Quartz clasts are subequally distributed between the two types of conglomerates. Quartzite and sandstone clasts are variably distributed between the two facies (0–67 percent and 0–32 percent, respectively). Clasts less than 15 mm were not measured, and some of the lithologies thus may not be recorded. Also, fine distinctions between similar lithologies (for example, shale and siltstone) were not made in the field.

Petrographic study showed that the average sandstone contained 44 percent quartz, 8 percent feldspar, 23 percent metamorphic rock fragments, 10 percent sedimentary rock fragments, 6 percent biotite, 3 percent muscovite, 3 percent calcite, 2 percent chert, and 1 percent detrital chlorite. The mineralogic compositions of individual samples are given in table 2. Most of the quartz grains contain numerous

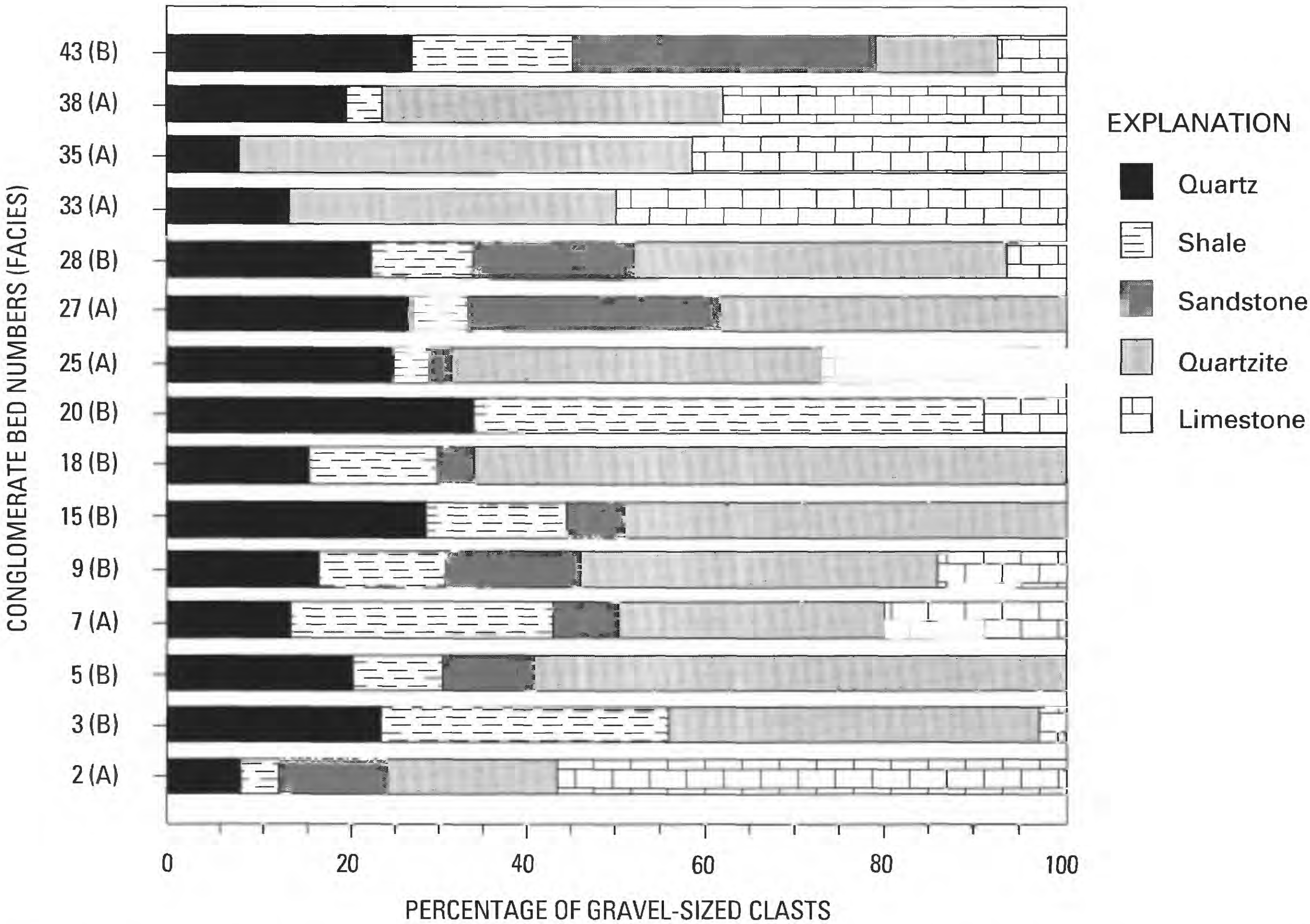

Figure 6. Observed vertical changes in major clast lithology for each conglomerate bed in the Dixon Quarry section. A denotes facies A (matrix-supported conglomerate), and B denotes facies B (clast-supported conglomerate).

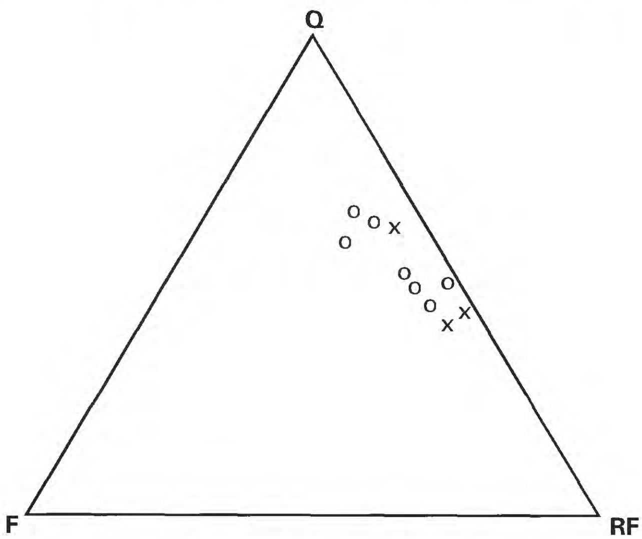

Figure 7. Sandstone (open circles) and conglomerate (crosses) matrix composition of the Fincastle syncline. Q is the percentage of quartz, F is the percentage of feldspar, and RF is the percentage of rock fragments (including chert).

vacuoles, bubble trains, and microlites. Some of the quartz grains are highly strained. Quartz extinctions vary from straight to undulose to semicomposite. Feldspar grains are dominantly plagioclase having compositions ranging from An_{50} to An_{55}. Some of the feldspar grains are replaced by calcite. Feldspar grains may be highly sericitized. Metamorphic rock fragments are most commonly quartzite, phyllite, meta-arkose, and slate. Uncommon fragments of schist were observed. Sedimentary rock fragments include siltstone, shale, limestone, and sandstone. Although matrix may constitute up to 40 percent of these sandstones, silica, calcite, hematite, and limonite cement may be present. Vermicular chlorite inclusions are common in quartz grains and as intergrowths between sand grains. Sandstone composition was normalized for quartz, feldspar, and rock fragment content and plotted on a triangular diagram (fig. 7).

Grain sizes range from very fine sand (0.08 mm) to coarse sand (0.51 mm), the mean grain size being 0.27 mm. The framework grains are subrounded to subangular. All of the samples were poorly or very poorly sorted. Two of these

Table 2. Mineralogic composition (in percent) of sandstone beds and sandy conglomerate matrices

[—, not detectable. Sample numbers refer to bed numbers assigned in stratigraphic section 1 (appendix A)]

Sample	Quartz	Feldspar	Morphic rock fragments	Sedimentary rock fragments	Calcite	Chert	Biotite	Muscovite	Detrital chlorite
				Sandstone beds					
4	41	8	23	15	—	4	5	4	—
17	46	8	30	8	—	2	3	1	2
19	44	3	38	10	—	1	1	1	2
23	44	8	26	10	5	—	2	4	1
26	48	8	10	9	7	3	7	8	—
37	43	12	12	7	7	—	16	—	3
Average	44	8	23	10	3	2	6	3	1
				Sandy conglomerate matrices					
7	42	5	13	8	9	4	8	8	3
25A	35	3	23	20	6	6	3	3	1
25B	26	—	22	41	3	6	1	1	—
Average	34	3	19	23	6	5	4	4	1

sandstones (17 and 19) are submature, as they contain less than 5 percent clay matrix but are poorly sorted. The other four sandstones are immature, as they contain greater than 5 percent clay matrix. The average composition of the conglomerate matrices studied is approximately 34 percent quartz, 3 percent feldspar, 19 percent metamorphic rock fragments, 23 percent sedimentary rock fragments, 6 percent calcite, 5 percent chert, 4 percent biotite, 4 percent muscovite, and 1 percent detrital chlorite. Mineralogic compositions of the individual samples are shown in table 2. Some of the quartz grains are quite strained, and most contain vacuoles, bubble chains, and microlites. Quartz extinctions range from straight to undulose to semicomposite. The two samples that contain feldspar are dominated by plagioclase (An_{50-55}). The metamorphic rock fragments are composed of quartzite, slate, phyllite, and meta-arkose. Sedimentary rock fragments observed include shale, siltstone, pelletal limestone, and sandstone (some having heavy mineral layers). Clay matrix may constitute up to 40 percent of the total matrix. Hematite, silica, and calcite cement may also be present. Vermicular chlorite inclusions are very common in quartz grains and in the matrix and as intergrowths between grains. Fragments of brachiopods and bryozoan are present in small amounts. The three samples of conglomerate matrix were normalized for quartz, feldspar, and rock fragment content and plotted on a triangular diagram (fig. 7). All of these samples were determined to be litharenites.

Grain sizes of the conglomerate matrix range from coarse silt (0.05 mm) to very coarse sand (1.80 mm), the mean grain size being 0.45 mm. The grains tend to be subrounded to subangular. All of the samples are very poorly sorted.

FACIES

From the many lithologies present in the Fincastle Conglomerate, eight facies were defined:

Facies A.... Matrix-supported granule to boulder conglomerate and coarse-grained to pebbly sandstones
Facies B.... Clast-supported granule to boulder conglomerate
Facies C.... Fine- to medium-grained sandstone
Facies D.... Laminated to bedded siltstone
Facies E.... Massive and finely laminated shale
Facies F.... Interbedded conglomerate, coarse-grained sandstone, and shale
Facies G.... Interbedded shale and sandstone
Facies H.... Gray and dusky-yellow shale marked by convolute bedding

Facies A consists of greenish-gray, olive-gray, grayish-orange, or grayish-red matrix-supported conglomerate and coarse-grained pebbly sandstone (fig. 8). This lithology is very poorly sorted. The beds are commonly 30 to 409 cm thick. The ratio of sand to mud is close to 1. Most of the beds have muddy matrices, but many have a high sand content. Mudstone clasts are common, and some are quite large, as much as 1.3 m long (fig. 9). Basal contacts are generally sharp and erosive and only rarely gradational. Most beds show normal grading, but some are random and disorganized. Some show clasts oriented parallel to bedding, and a few have load casts.

Facies B consists of dark-gray, greenish-gray, olive-gray, or grayish-orange clast-supported conglomerates (fig. 10). The beds are 34 to 170 cm thick. The ratio of sand to mud is high, as most of the matrix is composed of sandstone or has a high sand content. The basal contacts are sharp and erosive. Grading is variable in these deposits. Some show

Figure 8. Facies A. Matrix-supported conglomerate located near the lower contact of the Fincastle Conglomerate in Dixon Quarry. Note the erosional contact (EC) with the sandstone of facies C above. Coin is 17 mm in diameter.

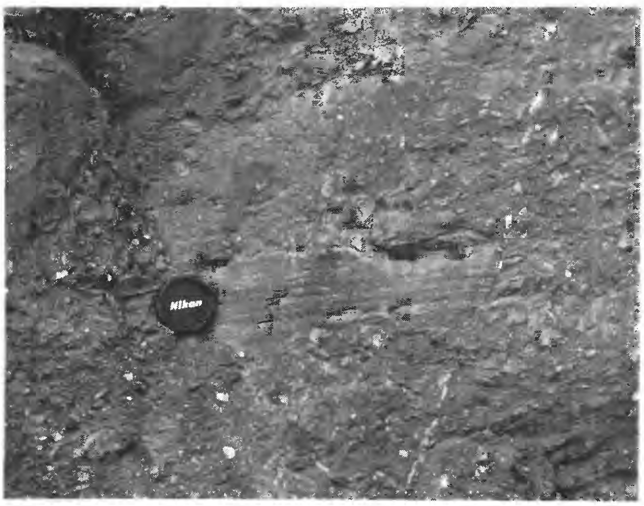

Figure 9. Large laminated mudstone clast (to the right of the lens cap) in facies A (matrix-supported conglomerate) in Dixon Quarry. Lens cap is 53 mm in diameter.

normal grading, and some show reverse grading at the base and a normal grading near the top. Others are very poorly sorted. Mudstone clasts are common and range from several centimeters to about 50 cm in length.

Facies C consists of yellowish-brown, light-brown, reddish-brown, brownish-gray, grayish-orange, or olive-gray fine- to medium-grained sandstone (fig. 11). These deposits are moderately to well sorted. The bed thickness ranges from 5 to 330 cm, but most are between 10 and 200 cm. The ratio of sand to mud is very high. The basal contacts are generally sharp and erosive, although some are

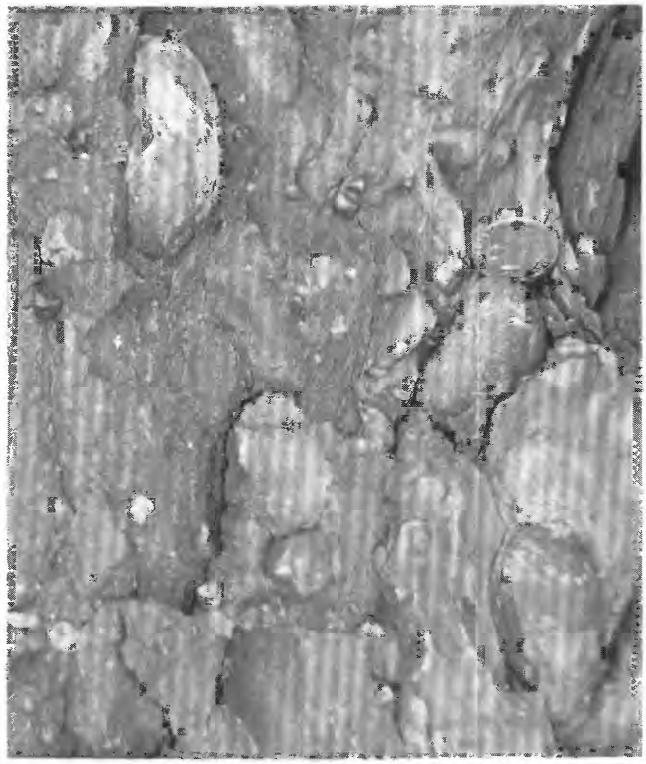

Figure 10. Facies B. Clast-supported conglomerate in the middle portion of the Dixon Quarry section. Bedding is horizontal. Coin is 17 mm in diameter.

gradational. No internal grading is apparent. Mudstone clasts are common at the base. Most beds appear to be massive. Some, however, show parallel laminations, ripples, or cross-laminations. These deposits may contain floating pebbles or pebbly lenses. Load casts and loaded flute casts are common.

Facies D consists of light- to dark-gray, well-laminated siltstone (fig. 12). The beds are generally 5 to 200 cm thick. The basal contacts are sharp and planar. No grading is apparent. The siltstone beds locally contain millimeter-thick laminae of sandstone or limestone composed of sand-sized fossil debris. Fossils within the siltstone proper are uncommon.

Facies E consists of olive- to dark-gray shale that is either finely laminated or massive (fig. 13). Most of the beds are 2 to 262 cm thick, but one bed measured 28.35 m. The basal contacts are usually sharp and planar, but some are irregular and erosive. The ratio of sand to mud is very low. Some of the beds contain centimeter-thick siltstone beds or pebble lenses.

Facies F consists of interbedded, discontinuous layers of coarse-grained sandstone, shale, and conglomerate (fig. 14) that are grayish orange, light brown, olive gray, or reddish brown in color. Bedding thicknesses range from 3.5 to 4.1 m. The ratio of sand to mud is high, as most of the conglomerates have a sandy matrix. The conglomerates

Figure 11. Facies C. Fine- to medium-grained sandstone in the upper portion of the Dixon Quarry section. Note the gravelly lens near the center of the unit and the planar laminations near the upper contact. Coin is 17 mm in diameter.

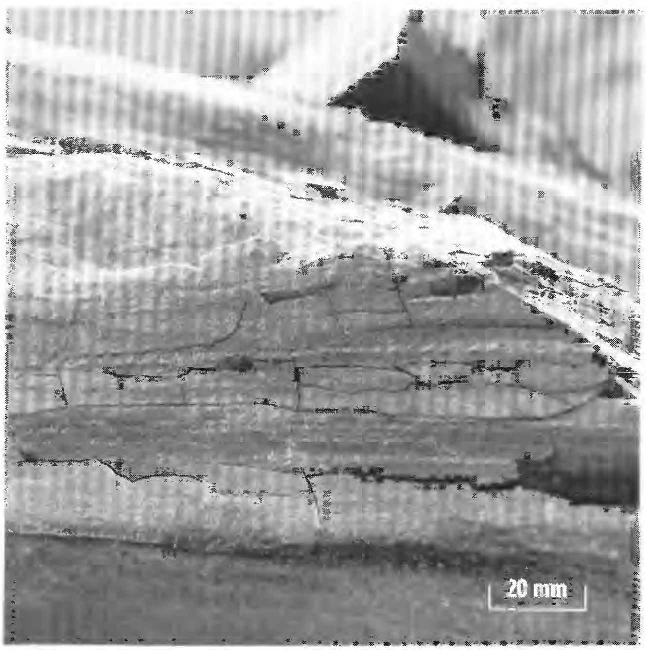

Figure 12. Facies D. Well-laminated siltstone in the upper portion of the Dixon Quarry section.

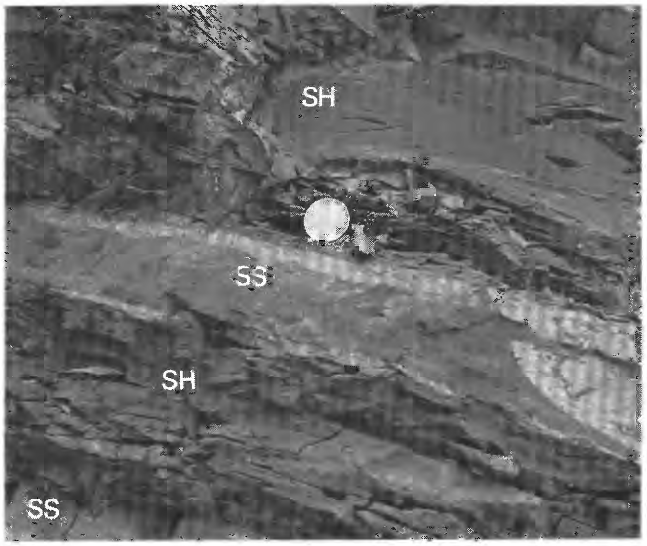

Figure 13. Facies E. Shale (SH) between two sandstone beds (SS) in the upper portion of the Dixon Quarry section. Coin is 17 mm in diameter.

may be either matrix or clast supported. Basal contacts are sharp and erosive. Contacts between the individual lithologies are also very sharp. No grading is apparent in the conglomerates. Interference ripples occur on the top of one of these beds. Load casts are present on the bases of some of the sandstones. Many of the shales show evidence of loading, and some contain convolute laminations. Small (several centimeters in length) mudstone clasts are common and are generally oriented parallel to bedding.

Facies G consists of interbedded olive-gray shale and brown, grayish-red, or olive-gray fine- to medium-grained sandstone (fig. 15). Some of the sandstones are slightly calcareous. The thickness of these units generally ranges from 23 to 57 cm but reaches a maximum of 6.5 m. The ratio of sand to mud is medium to low, as the shale beds tend to dominate these units. The basal contacts are generally sharp and erosive and locally planar. No grading is apparent within the sandstone beds. Both the sandstones and the shales are finely laminated. Floating pebbles or pebble lenses occur. "Flame" structures, also present, indicate soft sediment deformation of the shales.

Facies H consists of olive-gray and dusky-yellow convoluted shale (fig. 16). The shale is slightly calcareous and often contains wispy silt laminae. This facies ranges in thickness from 4 to 16 m. The ratio of sand to mud is very low. The basal contacts are sharp and planar. Convolute lamination is the most common sedimentary structure in this facies; folds range in amplitude from 5 mm to more than 1 m. Floating pebbles are present. Some of these beds contain fossils, including brachiopods, bryozoans, graptolites, and trilobites.

Field observations indicate that the idealized facies sequence is a fining- and thinning-upward sequence of (1)

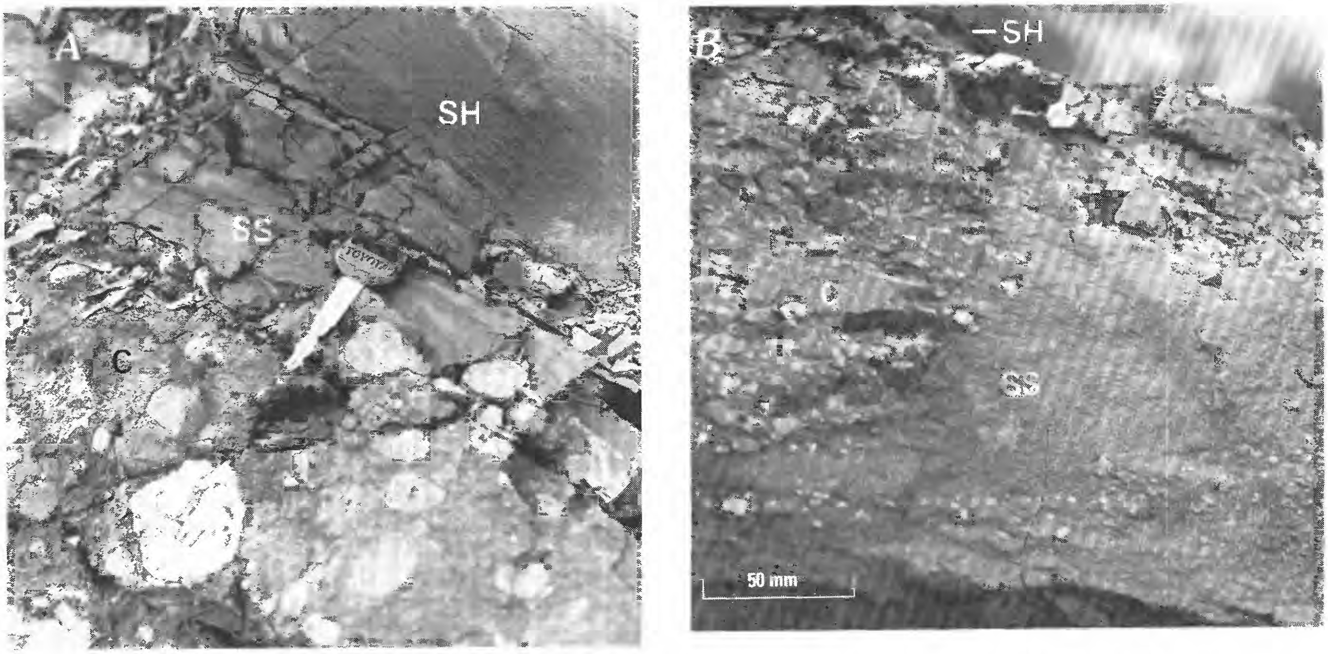

Figure 14. Facies F. Interbedded, discontinuous layers of coarse-grained sandstone (SS), shale (SH), and conglomerate (C) in Dixon Quarry. *A*, Key is 55 mm long. *B*, Bar scale is 50 mm long.

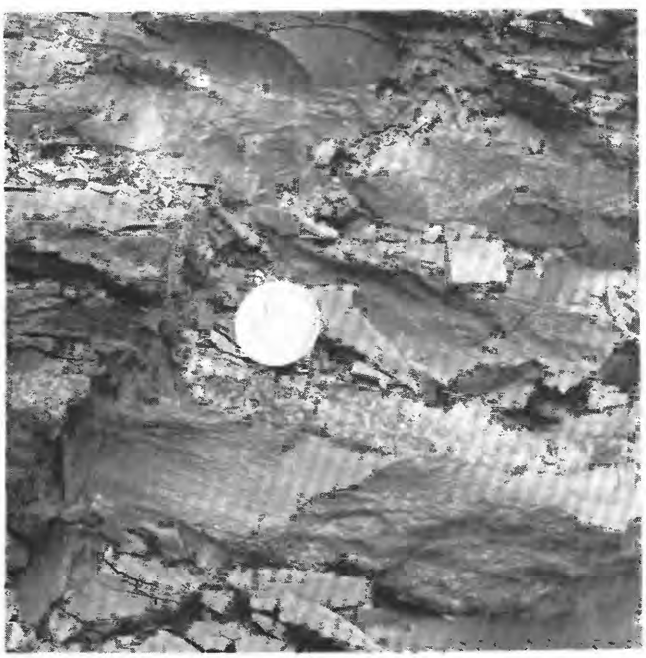

Figure 15. Facies G. Very thinly interbedded shale and fine- to medium-grained sandstone in the upper portion of the Dixon Quarry section. Coin is 17 mm in diameter.

coarse-grained conglomerates, both matrix and clast supported (facies A and B) to (2) finer grained, clast-supported conglomerates (facies B) to (3) fine- to medium-grained sandstone (facies C) to (4) shale (facies E) (fig. 17). Facies C and E may alternate somewhat toward the end of the cycle (fig. 18*A*), or the cycle may be capped by shale (fig. 18*B*).

DEPOSITIONAL PROCESSES AND ENVIRONMENTS OF DEPOSITION

Unlike marine biogenic sediments, which can accumulate in place, terrigenous sediments must be transported and deposited some distance after being eroded from land or the sea floor. The dominant transport mechanisms active on the continental slope were first recognized by analogy with subaerial mass movement (Dott, 1963). The three dominant processes are slides, rockfalls, and sediment gravity flows (Middleton and Hampton, 1973; Carter, 1975; Lowe, 1979; Nardin and others, 1979; Cook and others, 1982; Middleton and Southard, 1984; Stow, 1985). Slides involve shear failure along a discrete plane and can be classified as either glides or slumps. Glides occur along a planar surface, whereas slumps involve rotation in addition to the downslope movement. Rockfalls occur when individual clasts (sand to boulder sized) fall freely or roll from upper portions of very steep slopes such as reefs, fault scarps, or submarine canyon walls. The four basic types of sediment gravity flows are debris flows (also known as slurry flows and mud flows), grain flows, liquified and fluidized flows, and turbidity currents.

In debris flows, sand- to boulder-sized clasts are supported by the cohesive strength of a mud-water matrix-slurry. Sediment is supported in grain flows by grain-to-grain collisions, which create dispersive pressure. Grain

Figure 16. Facies H. Dislocated block of convolute laminated shale from the upper portion of the Dixon Quarry section. Lens cap is 53 mm in diameter.

flows are generally observed only on slopes steeper than 18° and persist only for very short distances. Liquified and fluidized flows are cohesionless flows in which the sediment is fully supported by the upward movement of fluids escaping from between the grains. Because of their high viscosity, liquified or fluidized flows can move rapidly down very low slopes (2°–10°) but only for short distances. Turbidity currents are initiated by the suspension of sediments in water and are thus much denser than the surrounding water.

Most of the depositional processes responsible for the eight facies displayed by the Fincastle Conglomerate can be described by evaluating mass sediment movement. Facies A (a matrix-supported conglomerate and pebbly sandstone) was probably deposited as a debris flow. This interpretation is supported by the disorganized nature of the clasts, the poor sorting, and the tendency toward a muddy matrix. Facies B (clast-supported conglomerate) has several possible interpretations. The beds that contain randomly oriented clasts may have been deposited by rockfalls. The beds displaying normal grading may have been deposited by high-concentration turbidity currents, the deposits showing only the "A" division of the Bouma sequence. Those beds that show reverse grading changing upward to normal grading may have been deposited initially by grain flows, the final deposition being from suspension. Facies C (fine- to medium-grained sandstone) is believed to represent deposition from grain flow. The massive nature of this facies, along with the unusual sole marks and faint laminations, supports this interpretation. Facies D (well-laminated siltstone) may have been deposited by low- to medium-density turbidity currents. Where the siltstone is thinly interbedded with sandstone or fossil debris, this unit might represent a "C–D" division of the Bouma sequence. Facies E (massive and laminated shale) is believed to have been deposited by pelagic or hemipelagic settling or by a nepheloid layer and is thus equivalent to Bouma's "E" division. Facies F (discontinuously interbedded layers of conglomerate, shale, and sandstone) probably originated as three discrete layers that were mixed and brecciated together as a result of slumping. Facies G (interbedded layers of shale and sandstone) are most likely the result of low- to medium-density turbidity currents. Their interbedded nature is characteristic of the base truncated Bouma sequence ("C–D–E"). Facies H (convolute laminated shale) may have been deposited by a liquefied or fluidized flow. The convolute laminations were formed as a result of escaping fluids. Although each of these facies can be assigned

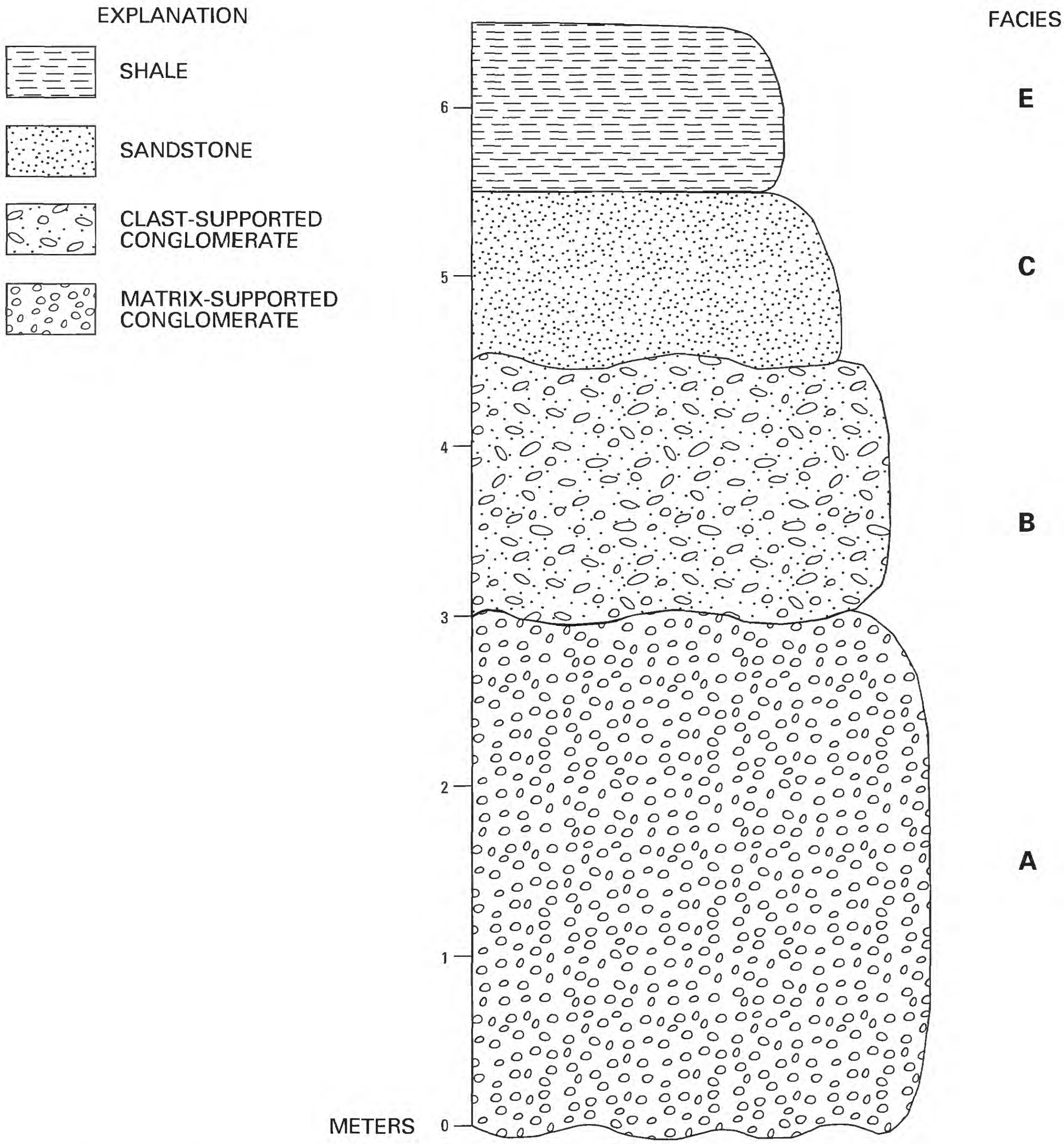

Figure 17. Idealized facies sequence showing a thinning- and fining-upward cycle.

tentatively to a depositional process, it should be emphasized that the processes described are end members of a continuous spectrum. Also, many different processes probably act on a flow throughout its existence, and only the characteristics of the final process are imparted to the sedimentary rock.

The Fincastle Conglomerate was probably deposited in a submarine canyon or a feeder channel to a submarine fan. The assemblages of lithofacies and the depositional processes likely represented by them are characteristic of both ancient (Walker, 1984) and modern (Shepard and others, 1969; Embly and Jacobi, 1986) submarine fans. Because many of these processes and lithologies are common to other environments (for example, alluvial fans or deltas), it is the position of the Fincastle Conglomerate within a series of marine units and the presence of marine fossils within the unit itself that distinguish it from other similar nonmarine deposits. The coarseness of this deposit dictates deposition in a channel. This channel must have been relatively close to the outer shelf, because most of the

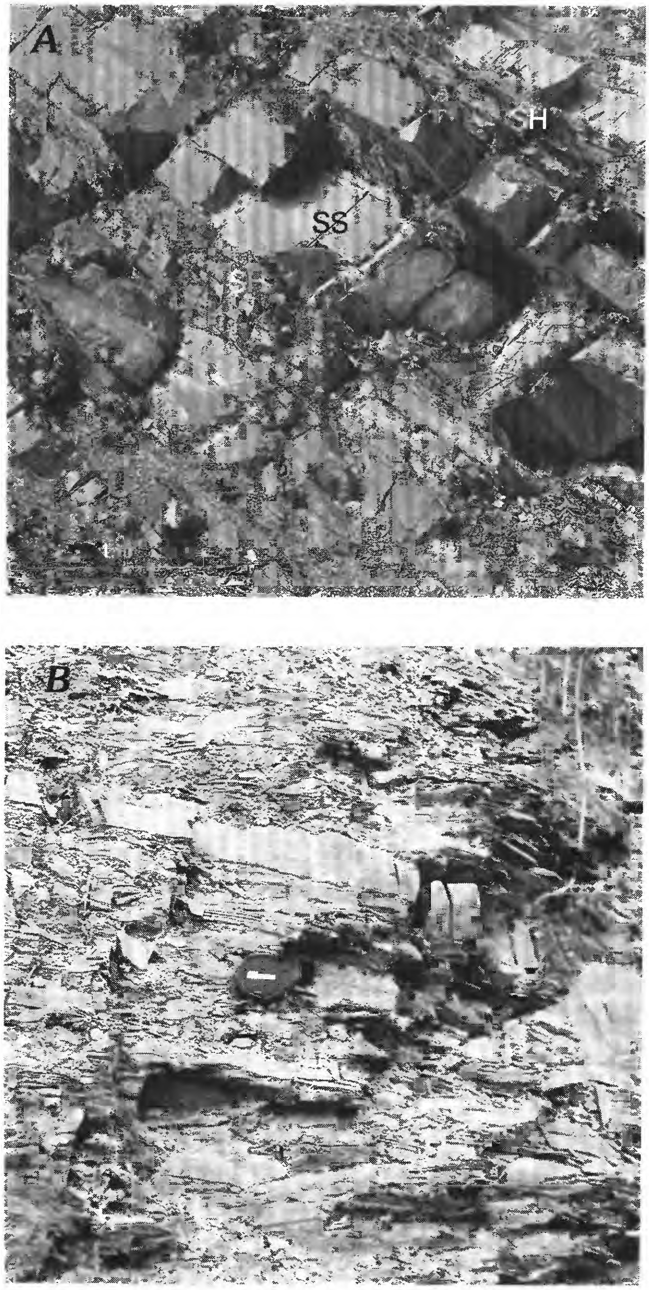

Figure 18. Alternations of facies C and E. *A*, Medium to thickly bedded sandstone (facies C) (SS) and shale (facies E) (SH) near the top of a cycle in the Dixon Quarry section. *B*, Thinly bedded sandstone (facies C) and shale (facies E) in Dixon Quarry. Lens cap is 53 mm in diameter.

processes represented here are known to persist only for short distances.

The main facies sequence seen in outcrops of the Fincastle consists of interbedded coarse conglomerates, sandstones, and shales in a thinning- and fining-upward package. This sequence is very similar to the small-scale thinning- and fining-upward sequence of the Cambrian-Ordovician Cap Enrage Formation in Quebec, Canada (Hein and Walker, 1982) and facies association 1 of the Upper Triassic Torlesse Zone in South Canterbury, New Zealand (Hicks, 1981). The "upward-thinning bedding cycles . . . probably reflect the gradual filling and abandonment of channels due to lateral migration . . . [and] the fine-grained interbeds may indicate overbank" deposits (Hicks, 1981, p. 219). Toward the upper portion of the Fincastle, sandstones and siltstones begin to dominate the section (facies C and D). This sequence is similar to the midfan facies association described in the Upper Cretaceous Great Valley sequence of northern and central California (Ingersoll, 1978) and facies association 2 of the Torlesse Zone (Hicks, 1981). Walker and Mutti (1973) described the middle fan channeled association as thick sandstone beds and minor conglomerates in braided channels associated with finer material (silts and shales) in the interchannel areas. A thinning- and fining-upward trend characterized by gradual abandonment results in the deposition of fine-grained beds (Walker and Mutti, 1973). The uppermost beds of the Fincastle are dominantly shale (facies E) and interbedded sand and shale (facies G) (fig. 18). Facies association 5 of the Torlesse Zone is composed of shale and sand packages and is believed to represent fan fringe deposition (Hicks, 1981). The composition of the Great Valley sequence is the same (Ingersoll, 1978).

"In . . . submarine canyons, deposition usually occurs in the waning stages of the canyon's life, typically initiating a retrogradational event" (Howell and Normark, 1982, p. 378). This sequence of events appears to be the one demonstrated by the Fincastle Conglomerate. The main facies sequence represents deposition in a major submarine channel that is progressively filled and abandoned during lateral migration. The sandy midfan portion of this body was deposited over the gravelly channel or inner fan area. As the sequence retrograded further, outer fan sediments were deposited over the midfan sediments. The carbonate shales and siltstones overlying the outer fan were deposited as a result of the return to a basin plain setting. This retrogradation was most likely caused by some combination of an eustatic sea-level rise, a decrease in tectonic activity, or a decrease in sediment flux (owing to either climatic or tectonic controls).

CONCLUSIONS

The lithologies, textures, and sedimentary structures of the Fincastle Conglomerate indicate deposition in a submarine channel near the edge of the outer shelf. This channel was progressively filled and abandoned owing to lateral migration. Some combination of tectonic, climatic, and sedimentological factors caused retrogradation of the channel and resulted in the deposition of midfan sands and outer fan sands and shales. A large section of convolute laminated shales was deposited during the final stages of this fan environment. The roundness of the gravel-sized clasts indicates that they were resedimented from another depositional environment (possibly a stream or delta) rather than eroded during the canyon formation. The extensive deformation of large mud clasts found in many of the beds suggests that they were unconsolidated at the time of deposition and eroded from the sea floor or canyon walls.

The lithologies of the gravel-sized clasts and the rock fragments of the sandstones indicate that they were derived from rocks of Cambrian and Ordovician ages in the Fincastle-Roanoke area. Quartzite, meta-arkose, metaconglomerate, sandstone, and shale clasts were probably derived from the Chilhowee Group. Phyllites and slates also may have been derived from the Chilhowee or the Rome Formation. The calcareous gray and red shale pebbles and rock fragments may have been eroded from the Rome Formation, the Liberty Hall Formation, or the Bays Formation. The Bays Formation probably also contributed sandstone and siltstone clasts. Limestone and chert clasts of the Fincastle were most likely derived from the Cambrian and Ordovician limestones and dolomites (Elbrook Limestone, Knox Group, New Market Limestone, Lincolnshire Limestone, Botetourt Limestone of Cooper and Cooper (1946)). No plutonic or volcanic clasts were observed. Furthermore, no clasts could be attributed to derivation from the Blue Ridge Precambrian basement (the Marshall Metagranite), as previous workers had reported (Decker, 1952; Tillman and Lowry, 1971; Lowry and others, 1972; Lowry, 1974; Karpa, 1974). Therefore, the theory that the basement of the Blue Ridge complex or the western Piedmont contributed to the sediments of the Fincastle is not supported by this study. However, it is clear that erosion had cut through the stratigraphic sequence down into the Chilhowee Group by the Middle Ordovician.

As part of the Middle Ordovician clastic wedge, the Fincastle Conglomerate is an important record of the early tectonic events and the paleoenvironments of the Appalachian basin. As more research is completed on ancient and modern submarine fans—and particularly on the conglomerates associated with them—understanding of the Fincastle should be greatly enhanced.

REFERENCES CITED

Amato, R.V., 1974, Geology of the Salem quadrangle, Virginia: Virginia Division of Mineral Resources Report of Investigations 37, 40 p.

Andrews, L.E., 1952, Structure of the area north of Roanoke, Virginia: Baltimore, Md., Johns Hopkins University, unpublished Ph.D. dissertation, 126 p.

Bartholomew, M.J., Schultz, A.P., Henika, W.S., and Gathright, T.M., II, 1982, Geology of the Blue Ridge and the Valley and Ridge at the junction of the central and southern Appalachians, *in* Lyttle, P.T., ed., Central Appalachian geology: Combined Northeastern-Southeastern Section, Geological Society of America Field Trip Guidebooks, p. 121–170.

Butts, C., 1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin 52, 568 p.

Campbell, H.D., 1905, The Cambro-Ordovician limestones of the middle portion of the Valley of Virginia: American Journal of Science, 4th ser., v. 20, p. 445–447.

Carter, R.M., 1975, A discussion and classification of subaqueous mass-transport with particular application to grain-flow, slurry-flow, and fluxoturbidites: Earth Science Reviews, v. 11, p. 145–177.

Cook, H.E., Field, M.E., and Gardner, J.V., 1982, Characteristics of sediments on modern and ancient continental slopes, *in* Schollee, P.A., and Spearing, D.R., eds., Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, p. 365–404.

Cooper, B.N., 1960, The geology of the region between Roanoke and Winchester in the Appalachian Valley of Western Virginia, *in* Guidebook 2: Johns Hopkins University Studies in Geology 18, 84 p.

Cooper, B.N., and Cooper, G.A., 1946, Lower Middle Ordovician stratigraphy of the Shenandoah Valley, Virginia: Geological Society of America Bulletin, v. 57, no. 1, p. 35–114.

Cooper, G.A., 1956, Chazyan and related brachiopods: Smithsonian Miscellaneous Collections, v. 127, pt. 1, p. 1–1024.

Cullather, C.M., 1988, The depositional environment of the Fincastle Conglomerate near Roanoke, Virginia: Washington, D.C., George Washington University, unpublished M.Sci. thesis, 110 p.

Decker, C.E., 1952, Stratigraphic significance of graptolites of Athens Shale: American Association of Petroleum Geologists Bulletin, v. 36, p. 11–145.

Dott, R.H., Jr., 1963, Dynamics of subaqueous gravity depositional processes: American Association of Petroleum Geologists Bulletin, v. 47, p. 104–128.

Embly, R.M., and Jacobi, R., 1986, Mass wasting in the western North Atlantic, *in* Vogt, P.A., and Tucholke, B.E., eds., The geology of North America, v. M, The western North Atlantic region: Boulder, Colo., Geological Society of America, p. 479–490.

Hein, F.J., and Walker, R.G., 1982, The Cambro-Ordovician Cap Enrage Formation, Quebec, Canada: Conglomeratic deposits of a braided submarine channel with terraces: Sedimentology, v. 29, p. 309–329.

Hicks, D.M., 1981, Deep-sea fan sediments in the Torlesse zone, Lake Ohau, South Canterbury, New Zealand: New Zealand Journal of Geology and Geophysics, v. 24, p. 209–230.

Howell, D.G., and Normark, W.R., 1982, Sedimentology of submarine fans, *in* Scholle, P.A., and Spearing, D.R., eds., Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, p. 365–404.

Ingersoll, R.V., 1978, Submarine fan facies of the Upper Cretaceous Great Valley Sequence, Northern California: Sedimentary Geology, v. 21, p. 205–230.

Karpa, J.B., III, 1974, The Middle Ordovician Fincastle Conglomerate north of Roanoke, Virginia, and its implications for Blue Ridge tectonism: Blacksburg, Virginia Polytechnical Institute and State University, unpublished M.Sci. thesis, 164 p.

Kellberg, J.M., and Grant, L.F., 1956, Coarse conglomerates of the Middle Ordovician in the Southern Appalachian valley: Geological Society of America Bulletin, v. 67, p. 697–716.

Lowe, D.R., 1979, Sediment gravity flows: Their classification and some problems of application to natural flows and

deposits: Society of Economic Paleontologists and Mineralogists Special Publication 27, p. 75–82.
Lowry, W.D., 1974, North American geosynclines—Test of the continental drift theory: American Association of Petroleum Geologists Bulletin, v. 58, p. 575–620.
Lowry, W.D., McDowell, R.C., and Tillman, C.G., 1972, The Diamond Hill and Fincastle conglomerates—Evidence of great structural relief between the Blue Ridge anticlinorium and Salem synclinorium in Middle Ordovician time [abs.]: Geological Society of America Abstracts with Programs, v. 2, no. 4, p. 88.
McBride, E.F., 1962, Flysch and associated beds of the Martinsburg Formation (Ordovician), Central Appalachians: Journal of Sedimentary Petrology, v. 32, p. 39–91.
McGuire, O.S., 1970, Geology of the Eagle Rock, Oriskany, and Salisbury quadrangles, Virginia: Virginia Division of Mineral Resources Report on Investigations 24, 39 p.
Middleton, G.V., and Hampton, M.A., 1973, Sediment gravity flows: Mechanics of flow and deposition, *in* Turbidites and deep-water sedimentation: Society of Economic Paleontologists and Mineralogists Pacific Section Short Course, Anaheim, Calif., 1973, p. 1–38.
Middleton, G.V., and Southard, J.B., 1984, Mechanics of sediment movement: Society of Economic Paleontologists and Mineralogists Eastern Section Short Course 3, Providence, R.I., 1984, p. 327–360.
Nardin, T.R., Hein, F.J., Gorsline, D.S., and Edwards, B.D., 1979, A review of mass movement processes, sediment and acoustic characteristics, and contrasts in slope and base-of-slope systems versus canyon-fan-basin floor systems: Society of Economic Paleontologists and Mineralogists Special Publication 27, p. 61–73.
Nichol, R.F., 1959, Geology and mineral resources of the Tinker Mountain-Fincastle, Virginia area: Blacksburg, Virginia Polytechnical Institute and State University, unpublished M.Sci. thesis, 86 p.
Rader, E.K., and Gathright, T.M., II, 1986, Stratigraphic and structural features of Fincastle Valley and Eagle Rock Gorge, Botetourt County, Virginia, *in* Geological Society of America Centennial Field Guide, Southeastern Section: Boulder, Colo., p. 105–108.
Read, J.F., 1980, Carbonate ramp-to-basin transitions and foreland basin evolution, Middle Ordovician, Virginia Appalachians: American Association of Petroleum Geologists Bulletin, v. 64, p. 1575–1612.
Shepard, F.P., Dill, R.F., and Von Rad, U., 1969, Physiography and sedimentary processes of La Jolla submarine fan and fan-valley, California: American Association of Petroleum Geologists Bulletin, v. 53, p. 390–420.
Stow, D.A.V., 1985, Deep-sea clastics: Where are we and where are we going?, *in* Brenchley, P.J., and Williams, B.P.J., eds., Sedimentology: Recent developments and applied aspect: Boston, Blackwell Scientific Publications, p. 67–93.
Stow, H.M., and Bierer, J.C., 1937, Some significance of the Athens conglomerate near Fincastle, Virginia [abs.], *in* Minutes of the Fifteenth Annual Meeting: Virginia Academy of Science Proceedings 1936–1937, p. 71.
Tillman, C.G., and Lowry, W.D., 1971, The Salem synclinorium—A treasury of Appalachian tectonic history, *in* Lowry, W.D., Tillman, C.G., Fara, M., and Kettren, L.P., Jr., Guidebook to contrast in style of deformation of the southern and central Appalachians of Virginia: Virginia Polytechnical Institute Department of Geologic Sciences Guidebook 6, p. 23–68.
———1973, Conodonts from the Fincastle conglomerate, Virginia [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 4, p. 359.
Walker, R., 1984, General introduction: Facies, facies sequences, and facies models, *in* Walker, R.G., ed., Facies models (2d ed.): Geoscience Canada Reprint Series 1, p. 1–7.
Walker, R., and Mutti, E., 1973, Turbidite facies and facies associations, *in* Turbidites and deep-water sedimentation: Society of Economic Paleontologists and Mineralogists Pacific Section Short Course, Anaheim, Calif., 1973, p. 119–157.

APPENDIXES

APPENDIX A: STRATIGRAPHIC SECTIONS

Section locations shown in figure 4. Graphic representations shown in figures A1 and A2. Bed numbers are those referred to in table 2, figures A1 and A2, and appendix B. Bed thicknesses are given in parentheses after each description.

Stratigraphic Section 1

Top of section

81. Siltstone, light gray (N7), well laminated, calcareous; thinly bedded with very fine grained, dusky yellow (5 Y 6/4), calcareous sandstone. (38.10 m)

Covered. (17.48 m)

80. Siltstone, sandstone, and fine layers of fossil debris, light gray (N7), thinly bedded in cycles. (0.91 m)
79. Shale, medium gray (N5), well laminated, very fissile, somewhat calcareous. Partially covered. Moved from outcrop to stream bed to measure. (28.35 m)

Minor fault, covered at base, runs up to soil horizon, downdip lineations on surface. N. 65° E., 66° SE.

78. Shale, olive gray (5 Y 4/1), finely laminated. (0.30 m)
77. Sandstone, grayish red (10 R 4/2), very fine grained, finely laminated, calcareous. (0.15 m)
76. Shale, olive gray (5 Y 4/1), very finely laminated, thinly interbedded with grayish red (10 R 4/2), very fine grained, finely laminated, calcareous sandstone. (0.23 m)
75. Sandstone, grayish red (10 R 4/2), very fine grained, finely laminated, calcareous. (0.10 m)
74. Shale, olive gray (5 Y 4/1), very finely laminated, thinly bedded, calcareous. (0.76 m)
73. Sandstone, grayish red (10 R 4/2), medium grained, evenly medium bedded, calcareous. (0.30 m)
72. Shale, olive gray (5 Y 4/1), well laminated, calcareous. (0.25 m)
71. Sandstone, light brownish gray (5 YR 6/1), very fine grained, finely laminated, calcareous. (0.15 m)
70. Shale, medium light gray (N6) and dusky yellow (5 Y 6/4); highly convoluted, folds ranging in size from 5 mm to greater than 1 m; calcareous. (3.96 m)
69. Siltstone, medium dark gray (N4), medium bedded, ripples(?) on bedding surfaces, very sparsely fossiliferous (*Lingula*); severely weathered on most surfaces, possibly a faulted zone. (48.15 m)
68. Shale, medium light gray (N6), dark gray (N3), and dusky yellow (5 Y 6/4); highly convoluted, folds ranging in size from 5 mm to greater than 1 m; calcareous, fossiliferous (brachiopods, bryozoans, trilobites, graptolites, bivalves), becoming more fossiliferous toward the top of the bed; rare pebbles (limestone, shale, rare well-rounded quartz) floating throughout the bed. (15.85 m)
67. Shale, olive gray (5 Y 4/1), very fissile, partially covered; possibly the base of the thick, convoluted shale bed; contacts covered. (1.22 m)
66. Siltstone, medium light gray (N6), somewhat muddy, laminated and cross-laminated. (0.86 m)
65. Sandstone, grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4), upper fine grained, cross-laminated. (0.36 m)
64. Silty shale mottled medium dark gray (N4) and white (N9), fissile, commonly rippled. (0.64 m)
63. Sandstone, very fine grained, light olive gray (5 Y 6/1) to greenish gray (5 GY 6/1), ripple cross-lamination. N. 70° E., 46° S. (0.46 m)
62. Silty shale mottled medium dark gray (N4) and white (N9), fissile, slightly calcareous. (0.30 m)
61. Sandstone, very fine grained, medium light gray (N6); shows cross-laminations and ripples. (0.74 m)
60. Silty shale, olive gray (5 Y 4/1) to light gray (N7), well laminated, very fissile; few light-brown (5 YR 6/4) sandy layers in base only. (0.25 m)
59. Sandstone, light brown (5 YR 6/4), lower coarse grained, well laminated; indistinct cross-laminations; a few granule lenses of quartz and chert. (0.28 m)
58. Silty shale, light gray (N7) to light olive gray (5 Y 6/1), thinly bedded with olive gray (5 Y 4/1) fissile shale; millimeter-thick silty lenses; ripple cross-lamination. (1.73 m)
57. Sandstone, pale reddish brown (10 YR 6/2), upper medium grained, finely laminated. (0.05 m)
56. Sandstone, lower coarse grained, and pebble conglomerate, pale reddish brown (10 YR 6/2), irregularly interbedded in stringers with olive gray (5 Y 4/1) shale in an approximately even mix. (0.28 m)
55. Sandstone, moderate brown (5 YR 4/4), upper fine grained; contains lenses of olive gray (5 Y 4/1) shale; very discontinuously bedded; coarsens up into conglomerate with shale clasts in last 0.15 m. (3.25 m)
54. Siltstone, olive gray (5 Y 4/1), discontinuous. (0.05 m)
53. Sandstone, light to moderate brown (5 YR 5/6–5 YR 4/4), upper medium grained; interference ripples found on bedding surfaces; a few olive-gray (5 Y 4/1) shale interbeds. (0.35 m)
52. Shale, olive gray (5 Y 4/1), well laminated. (0.02 m)
51. Sandstone, dark olive gray (5 Y 3/1), upper fine grained. (0.05 m)
50. Shale, olive gray (5 Y 4/1), well laminated. (0.09 m)
49. Sandstone, light to moderate brown (5 YR 5/6–5 YR 4/4), upper medium grained; upper 5 cm are interbedded with olive gray shale (5 Y 4/1). (0.79 m)
48. Shale, olive gray (5 Y 4/1), finely bedded with light-brown medium-grained sandstone; ripples found on bedding surfaces; similar to bed 46 but containing more sand; upper contact scoured. (0.18–0.43 m)
47. Sandstone, light to moderate brown (5 YR 5/6–5 YR 4/4), lower coarse grained, massive; contains very minor shale clasts, ripples on top surface only. (0.43 m)
46. Shale, olive gray (5 Y 4/1), "lumpy" appearance owing to the content of approximately 50 percent stringers of moderate brown (5 YR 4/4), medium-grained sandstone; quartz granules throughout; top surface scoured by overlying sandstone; pebbles found lower along contact. (0.28 m)
45. Sandstone, light to moderate brown (5 YR 5/6–5 YR 4/4), lower coarse grained; bulbous sole marks found on basal contact and ripples found on bedding surfaces; granule lenses found at base. (0.41 m)

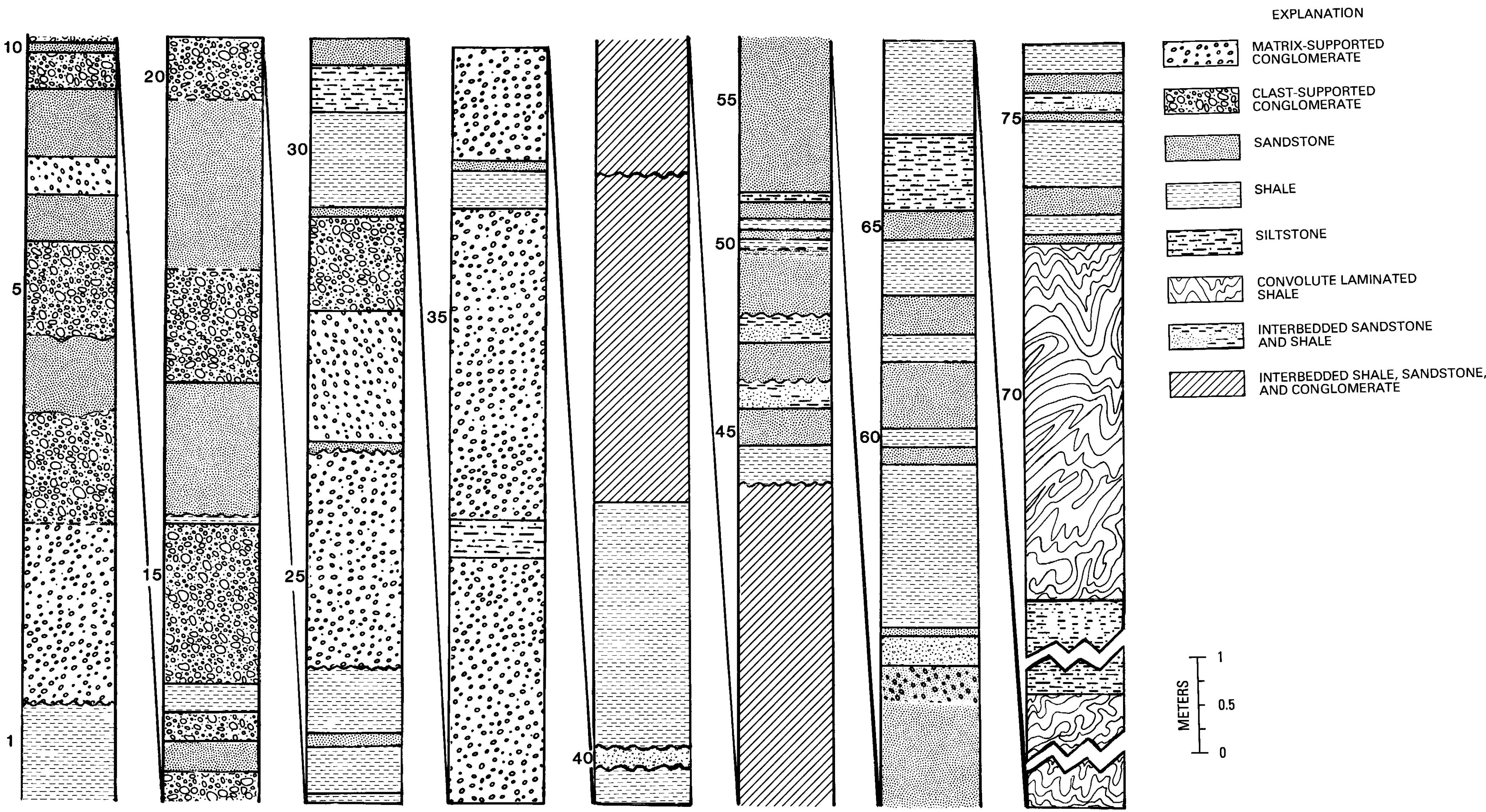

Figure A1. Stratigraphic section 1. Bed numbers correspond to those given in appendix A. For additional detail, see descriptions given in appendix A.

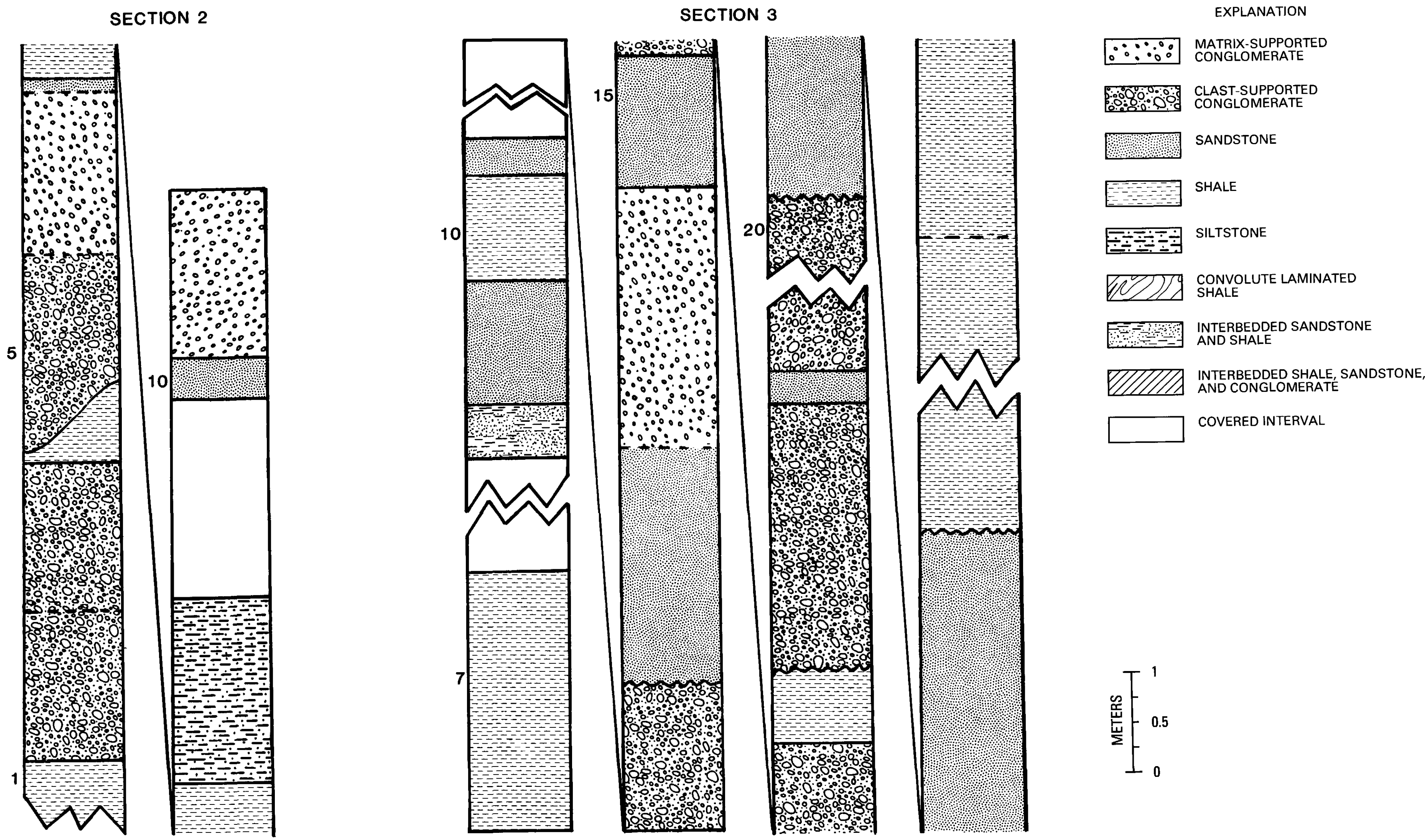

Figure A2. Stratigraphic sections 2 and 3. Bed numbers correspond to those given in appendix A. For additional detail, see descriptions given in appendix A.

44. Shale, olive gray (5 Y 4/1), contains minor sand stringers. (0.43 m)

43. Conglomerate, interbedded discontinuous layers. (1) Conglomerate, moderate to reddish brown (10 R 4/6), sandy matrix, granule- to pebble-sized clasts and rare cobbles, randomly oriented clasts, clast supported; clasts are of sandstone, quartzite, limestone, quartz, and shale; coarsens upward. (2) Sandstone, light brown (5 YR 6/4), lower coarse grained, subrounded; contains small intraformational shale clasts oriented parallel to bedding and pebbly lens of conglomerate, interference ripples and sole marks found on sandstone bedding surfaces. (3) Shale, olive gray (5 Y 4/1), convolute bedding, generally found as irregular clasts, may contain stringers of the sandstone. Most of the discontinuous units have sharp contacts between them. (4.09 m)

42. Sandstone, interbedded discontinuous lenses of (1) conglomerate, grayish orange (10 YR 7/4), sandy matrix, granule- to pebble-sized clasts, clast-supported; (2) sandstone, light brown (5 YR 6/4), lower coarse grained, well rounded, contains tiny shale clasts and interference ripples; (3) shale, olive gray (5 Y 4/1), fissile. (3.56 m)

41. Shale, olive gray (5 Y 4/1), laminated; contains irregular lenses of mudstone and medium-grained sandstone; minor single, floating pebbles throughout. (2.62 m)

40. Pebbly sandstone, dark to moderate yellowish brown (10 YR 4/2–10 YR 5/4), coarse grained, arkosic. (0.20 m)

39. Silty shale, olive gray (5 Y 4/1) to light olive gray (5 Y 6/1); finely laminated and fissile; contains unevenly distributed zones of pebbles. (0.38 m)

38. Conglomerate, dark olive gray (5 Y 3/1), upper medium-grained sandy matrix, granule- to cobble-sized clasts of grayish black quartzite, shale, limestone, quartz, and sandstone, matrix supported; larger clasts oriented parallel to bedding; fines upward; contains large, medium-dark-gray (N4) shale lenses. (1.20 m)

37. Sandstone, olive gray (5 Y 4/1) to light olive gray (5 Y 6/1), upper fine grained. (0.12 m)

36. Silty shale, olive gray (5 Y 4/1) to light olive gray (5 Y 6/1); finely laminated and fissile; contains unevenly distributed zones of pebbles. (0.38 m)

35. Conglomerate, dark olive gray (5 Y 3/1), granule-to cobble-sized clasts of grayish-black quartzite, shale, limestone, quartz, and sandstone, upper medium-grained sandy matrix, matrix supported; larger clasts oriented parallel to bedding; general fining-upward trend; contains large, medium-dark-gray (N4) shale lenses. (3.30 m)

34. Siltstone, light olive gray (5 Y 6/1), micaceous. (0.20–0.38 m)

33. Conglomerate, dark gray (N3) to grayish red (10 R 4/2); matrix is a fissile, slightly calcareous shale; pebble- to cobble-sized clasts of limestone, quartzite, and quartz, matrix supported; contains clasts of grayish black quartzite, shale, and sandstone; larger clasts oriented parallel to bedding at the base; matrix may show convolute laminations; contains large, medium-dark-gray (N4) shale lenses and lenses of upper coarse-grained grayish-orange sandstone (10 YR 7/4). (2.68 m)

32. Sandstone, medium gray (N5) to grayish orange (10 YR 7/4), upper medium grained, massive, discontinuous; interfingers laterally with siltstone bed 31. (0.27 m)

31. Siltstone, medium dark gray (N4) to grayish orange (10 YR 7/4), laminated, discontinuous; interfingers laterally with overlying sandstone bed 32; basal contact poorly exposed. (0.45 m)

30. Shale, olive gray (5 Y 4/1) showing patches of dusky red (5 R 3/4). (0.98 m)

29. Sandstone, light olive gray (5 Y 6/1), medium grained, contains indistinct cross-laminations. (0.06 m)

28. Conglomerate, light olive gray (5 Y 6/1), coarse sandy matrix; very large cobble-sized clasts of limestone, shale, quartz, sandstone and quartzite, clast supported; dramatic fining upward to just a pebbly sand in last 2 cm. (1.06 m)

27. Conglomerate, light grayish orange (10 YR 7/4), silty matrix, granule- to pebble-sized clasts of quartz, sandstone, shale, and quartzite, clasts randomly oriented, matrix supported; contains large lenticular clasts of laminated and convoluted medium-dark-gray (N4) and dusky-red (5 R 3/4) shale ranging in length from 0.20 to 1.0 m and oriented approximately parallel to bedding. (1.43 m)

26. Sandstone, medium light gray (N6), lower medium grained, contains indistinct ripple cross-lamination and lenses of pebble conglomerate; discontinuous, ends abruptly laterally against conglomerate below. (0.10 m)

25. Conglomerate, olive gray (5 Y 4/1), shaley matrix, pebble- to cobble-sized clasts of quartzite, limestone, sandstone, shale, and quartz, matrix supported; clasts chaotically oriented; general fining-upward trend; matrix may show convolute laminations; contains large, lenticular clasts of medium-dark-gray, finely laminated, rolled and folded shale ranging in length from 0.34 m to 1.30 m; conglomerate scours into shale below. (2.35 m)

24. Shale, medium dark gray (N5), very finely laminated; contains several 2- to 5-cm-thick medium-dark-gray, sandy siltstone beds and floating pebbles. (0.71 m)

23. Sandstone, medium gray (N5), lower fine grained, massive. (0.06–0.12 m)

22. Shale, medium dark gray (N4), very finely laminated. (0.53 m)

21. Shale, medium dark gray (N4), very finely laminated; compressed between sandstone bed 19 and conglomerate bed 20; interfingers laterally with the underlying sandstone and conglomerate. (0.10–0.20 m)

20. Conglomerate, greenish gray (5 GY 6/1) to grayish orange (10 YR 7/4), matrix of lower fine-grained, grayish-orange (10 YR 7/4) sandstone, granule- to cobble-sized clasts of quartzite, shale, and quartz, clast supported, very poorly sorted; interfingers laterally with underlying sandstone. (0.57–0.77 m)

19. Sandstone, grayish orange (10 YR 7/4), lower fine grained, massive; contains medium-dark-gray (N4), finely laminated, convoluted shale clasts; interfingers laterally with overlying conglomerate; thickens and thins dramatically; upper contact poorly exposed. (1.84 m (?))

18. Conglomerate, greenish gray (5 GY 6/1) to grayish orange (10 YR 7/4), matrix of lower fine-grained, grayish-orange (10 YR 7/4) sandstone, granule- to cobble-sized clasts of quartzite, sandstone, quartz, and shale, clast supported, very poorly sorted; coarsens upward slightly before fining upward into and interfingering laterally with overlying sandstone. (1.35 m)

17. Sandstone, grayish orange (10 YR 7/4), lower fine grained, massive; contains a few medium-dark-gray (N4), finely laminated shale clasts along lower contact; interfingers laterally with conglomerate. (1.42 m)
16. Shale, olive gray (5 Y 4/1), thinly bedded, contains a few stray pebbles; separated and thinned along contact between sandstone and conglomerate. (0.10–0.15 m)
15. Conglomerate, greenish gray (5 GY 6/1) to grayish orange (10 YR 7/4), sandy matrix, granule- to cobble-sized clasts of sandstone, quartzite, shale, and quartz, clast supported, very poorly sorted; large clasts up to approximately 0.60 m long of medium-dark-gray (N4) shale and stray pebbles; discontinuous beds of lower fine-grained, grayish-orange sandstone; thins somewhat laterally; partially covered. (1.70 m)
14. Shale, olive gray (5 Y 4/1), finely bedded, contains a few stray pebbles. (0.28 m)
13. Conglomerate, silty matrix, grayish orange (10 YR 7/4), pebble- to cobble-sized clasts, clast supported; mostly covered. (0.34 m)
12. Sandstone, grayish orange (10 YR 7/4), lower fine grained, contains a few floating granules; thins laterally. (0.35–0.18 m)
11. Conglomerate, grayish orange (10 YR 7/4), silty matrix, pebble- to cobble-sized clasts, clast supported; mostly covered. (0.36 m)
10. Sandstone, grayish orange (10 YR 7/4), lower fine grained, contains a few floating pebbles and pebble lenses. (0.05 m)
9. Conglomerate, grayish orange (10 YR 7/4), silty matrix, pebble- to cobble-sized clasts of limestone, shale, quartz, sandstone, and quartzite, clast supported; General fining-upward trend; rarely has larger clasts located near upper contact; partially covered. (0.39 m)
8. Sandstone, grayish orange (10 YR 7/4), lower fine grained, contains a few floating pebbles and pebble lenses. (0.70 m)
7. Conglomerate, greenish gray (5 GY 6/1) to grayish orange (10 YR 7/4), silty matrix, pebble-sized clasts of quartz, sandstone, limestone, and shale, matrix supported; the flattened pebbles appear imbricated; generally fines upward, although several larger clasts are found near the upper contact; contains a few small intraformational shale clasts (<0.20 m). (0.43 m)
6. Sandstone, olive gray (5 Y 4/1) to yellowish gray (5 Y 8/1), lower fine grained; contains a few pebble lenses and floating clasts, particularly near the upper contact; thins laterally. (0.50 m)
5. Conglomerate, greenish gray (5 GY 6/1) to grayish orange (10 YR 7/4), silty matrix, pebble-sized clasts of shale, quartzite, sandstone, and quartz, clast supported; contains several lenses of grayish-orange (10 YR 7/4), medium-grained sand; scoured lower contact; poorly exposed. (1.05 m)
4. Sandstone, moderate yellowish brown (10 YR 5/4), lower medium grained, massive, discontinuous. (0.80 m)
3. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), silty matrix, pebble- to cobble-sized clasts of sandstone, quartzite, quartz, and shale, clast supported; many of the elongate clasts are oriented parallel to bedding; moderately well sorted; coarsens, then fines upward; small intraformational shale clasts, about 0.30 m, along basal contact. (1.14 m)
2. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), silty matrix, pebble- to cobble-sized clasts of sandstone, shale, quartz, and quartzite, matrix supported; many elongate clasts are oriented parallel to bedding; gradual but dramatic fining upward; scoured lower contact. (1.90 m)
1. Shale, olive gray (5 GY 4/1) to dusky yellow (5 Y 6/4), free of clasts, convoluted bedding with folds ranging from 1 to 30 mm; contains wispy laminations of silt. (3.53 m)

Bottom of section

Stratigraphic Section 2

Top of section

11. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), medium-grained sandy matrix, granule- to cobble-sized clasts of limestone, quartz, shale, sandstone, and quartzite, matrix supported. (1.65 m)
10. Sandstone, medium dark gray (N4) to grayish orange (10 YR 7/4), finely bedded. (0.38 m)

Covered. (Approximately 2.00 m)

9. Siltstone and sandstone interbedded, medium dark gray (N4) to grayish orange (10 YR 7/4), finely bedded; possibly coarsens up into sandstone above. (1.86 m)

Moved approximately 20 m to the northwest.

8. Shale, olive gray (5 Y 6/1), fissile, contains thin discontinuous beds of conglomerate similar to the beds below (15 m thick). (0.91 m)
7. Sandstone, medium dark gray (N4) to grayish orange (10 YR 7/4), medium grained, contains rare floating pebbles; thickens laterally to about 1 m. (0.20 m)
6. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), granule- to pebble-sized clasts of quartz, laminated shale, sandstone, and quartzite, medium-grained sandy matrix, matrix supported; grades up into overlying sandstone. (1.50 m)
5. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), pebble-sized clasts of quartz, laminated shale, sandstone, and quartzite, medium-grained sandy matrix, clast supported; contains discontinuous beds of grayish-orange (10 YR 7/4) sandstone and olive-gray (5 Y 4/1) shale; grades up into overlying pebble conglomerate. (1.50 m)
4. Shale, light olive gray (5 Y 6/1), silty, very fissile. Discontinuous (goes from 0.81 m to nothing laterally over a short distance). (0.00–0.81 m)
3. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), pebble- to cobble-sized clasts of quartz, laminated shale, sandstone, and quartzite, medium-grained sandy matrix, clast supported; contains discontinuous beds of grayish-orange (10 YR 7/4) sandstone and olive-gray (5 Y 4/1) shale; grades up into overlying pebble conglomerate. (1.50 m)
2. Conglomerate, medium dark gray (N4) to grayish orange (10 YR 7/4), pebble- to cobble-sized clasts of quartz, laminated shale, sandstone, and quartzite, medium-grained sandy matrix, clast supported; contains discontinuous beds of grayish-orange (10 YR 7/4) sandstone and olive-gray (5 Y 4/1) shale; grades up into overlying pebble and cobble

conglomerate; the first four conglomerate beds show a gradual decrease in grain size upward in what is basically the same lithology. (1.50 m)

1. Shale, light olive gray (5 Y 6/1), finely laminated to thinly bedded, very fissile; lower contact covered (Paperville Shale?).

Bottom of section

Stratigraphic Section 3

Covered. (6.58 m)

11. Sandstone, medium dark gray (N4) to grayish orange (10 YR 7/4), upper coarse grained, granular and gravelly; poorly exposed. (0.36 m)
10. Shale, medium dark gray (N4), well laminated, fissile. (0.97 m)
9. Sandstone, medium dark gray (N4) to grayish orange (10 YR 7/4), medium grained; rarely contains intraformational shale clasts (<1 cm); both lower and upper contacts are poorly exposed. (1.26 m)
8. Sandstone, medium dark gray (N4) to grayish orange (10 YR 7/4), medium grained, and shale, medium olive gray (5 Y 4/1), interbedded; demonstrates flame structure. (0.57 m)

Covered. (5.97 m)

7. Shale, medium dark gray (N4), well laminated, fissile, calcareous. (2.62 m)

Covered. Limestone, then shale float. (0.44 m)

Salem Fault

Covered. Limestone float. (60.41 m)

6. Limestone, medium dark gray (N4), slightly silty. (9.71 m)

Covered. Limestone float. (18.32 m)

5. Limestone, medium gray (N5), thinly bedded. 0.80 m Covered. (1.93 m)
4. Limestone, medium dark gray (N4), thinly bedded. (3.35 m)

Covered. (36.25 m)

3. Limestone, dark gray (N4), thinly bedded. (0.25 m)

Covered. (6.25 m)

2. Shale, medium dark gray (N4), finely laminated, slightly calcareous. (0.75 m)
1. Limestone, dark gray (N4), thinly bedded. (6.45 m)

Bottom of section

APPENDIX B. GRAIN-SIZE MEASUREMENTS OF GRAVEL-SIZED CLASTS

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
		Transect 31		
43	32	Quartz	29.1	Majority of clasts less than 15 mm.
	40	Shale		
	19	Sandstone		
	22	Quartz		
	20	Shale		
	32	Sandstone		
	24	.........do.........		
	47	Dark-green quartzite		
	24	Quartz		
	36	Sandstone		
	24	Shale		
		Transect 30		
43	39	Sandstone	22.1	
	40	Dark-green quartzite		
	15	Quartz		
	22	Gray limestone		
	24	Sandstone		
	20	Dark-green quartzite		
	15	Sandstone		
	15	Shale		
	15	Quartz		
	16	.........do.........		
	22	Gray limestone		
42				Conglomerate bed 42 too sparse to measure.
		Transect 29		
38	32	Dark-green quartzite	32.9	
	28	Gray limestone		
	24	Shale		
	42	Gray limestone		
	32	Dark-green quartzite		
	18	Gray limestone		
	16	Quartzite		
	54	.........do.........		
	19	Gray limestone		
	64	Crystalline limestone		
		Transect 28		
38	80	Dark-green quartzite	44.1	
	75	.........do.........		
	60	.........do.........		
	60	.........do.........		
	48	Gray limestone		
	45	Dark-green quartzite		
	33	Gray limestone		
	22	.........do.........		
	25	Quartz		
	48	Dark-green limestone		
	54	.........do.........		
	15	Quartzite		
	25	Gray limestone		
	28	Quartz		

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
		Transect 27		
35	58	Gray limestone	41.4	
	49	Crystalline limestone		
	20	Gray limestone		
	15	Quartz		
	18	Gray limestone		
	15	Crystalline limestone		
	49	Dark-green limestone		
	92	Gray limestone		
	80	Dark-green quartzite		
	64	.........do.........		
	18	Gray limestone		
	19	.........do.........		
		Transect 26		
35	80	Gray limestone	39.8	
	47	Dark-green quartzite		
	38	Gray quartzite		
	22	Gray limestone		
	48	Dark-green quartzite		
	50	.........do.........		
	92	.........do.........		
	48	Crystalline limestone		
	15	Shale		
	15	.........do.........		
	15	Shale		
	38	Dark-green quartzite		
	32	.........do.........		
	32	Crystalline limestone		
	21	Quartz		
	15	.........do.........		
	28	Crystalline limestone		
	18	Dark-green quartzite		
	28	Gray limestone		
	76	.........do.........		
	24	Dark-green quartzite		
	79	.........do.........		
	54	Gray limestone		
		Transect 25		
35	40	Dark-green quartzite	47.5	
	80	Gray limestone		
	46	Crystalline limestone		
	38	Dark-green quartzite		
	58	Black quartzite		
	47	Dark-green quartzite		
	50	Crystalline limestone		
	25	Dark-green quartzite		
	58	Shale		
	43	Dark-green quartzite		
	30	.........do.........		
	31	.........do.........		
	41	.........do.........		
	78	Crystalline limestone		
		Transect 24		
33	15	Gray limestone	29.0	
	21	.........do.........		
	37	.........do.........		
	22	Dark-green quartzite		
	18	Gray limestone		

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
Transect 24—Continued				
	22	.........do.........		
	18	Dark-green quartzite		
	40	Gray limestone		
	47	Dark-green quartzite		
	48	.........do.........		
	18	Quartz		
	23	.........do.........		
	32	Gray limestone		
	45	Dark-green quartzite		
Transect 23				
28.....	85	Dark-green quartzite	73.1	
	83	Gray limestone		
	23	Dark-green quartzite		
	99	.........do.........		
	15	Shale		
	42	Quartz		
	57	.........do.........		
	89	Dark-green quartzite		
	57	.........do.........		
	24	Shale		
	79	Sandstone		
	160	Dark-green quartzite		
	27	.........do.........		
	48	.........do.........		
	28	Quartz		
	80	.........do.........		
	140	Sandstone		
	180	.........do.........		
Transect 22				
27.....	25	Dark-green quartzite	21.5	Majority of clasts <15 mm.
	20	Shale		
	18	Sandstone		
	32	Dark-green quartzite		
	17	Quartz		
	17	Sandstone		
Transect 21				
27.....	15	Dark-green quartzite	18.8	Majority of clasts <15 mm.
	15	Quartz		
	20	Dark-green quartzite		
	25	Sandstone		
Transect 20				
27.....	17	Quartz	23.2	Majority of clasts <15 mm.
	23	Sandstone		
	27	Dark-green quartzite		
	29	.........do.........		
	20	Quartz		
Transect 19				
25.....	15	Dark-green quartzite	17.8	
	26	Gray limestone		
	16	Dark-green quartzite		
	15	Quartz		
	15	Dark-green quartzite		
	15	Quartz		
	20	Gray limestone		
	15	Quartz		
	15	.........do.........		
	24	Dark-green quartzite		
	18	.........do.........		
	20	Gray limestone		
	18	Quartz		

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
Transect 18				
25.....	17	Dark-green quartzite	26.3	
	15	.........do.........		
	15	Quartz		
	15	Dark-green quartzite		
	40	.........do.........		
	22	Quartz		
	30	Shale		
	15	Dark-green quartzite		
	15	Quartz		
	34	.........do.........		
	34	Gray limestone		
	22	Sandstone		
	22	Gray limestone		
	28	Dark-green quartzite		
	35	.........do.........		
	27	.........do.........		
	50	.........do.........		
	28	Sandstone		
Transect 17				
25.....	15	Quartz	43.8	
	30	Dark-green quartzite		
	35	.........do.........		
	39	Gray limestone		
	17	.........do.........		
	48	.........do.........		
	110	Dark-green quartzite		
	36	Gray limestone		
	77	.........do.........		
	92	Dark-green quartzite		
	50	Gray limestone		
	52	Dark-green quartzite		
	15	.........do.........		
	22	Gray limestone		
	80	Quartz		
	38	Dark-green quartzite		
	15	Gray limestone		
	18	Quartz		
Transect 16				
20.....	20	Shale	33.9	
	21	.........do.........		
	62	Dark-green quartzite		
	40	Quartz		
	50	Shale		
	27	Quartz		
	19	Shale		
	24	.........do.........		
	42	Quartz		
Transect 15				
18.....	70	Dark-green quartzite	42.7	
	87	.........do.........		
	30	.........do.........		
	67	.........do.........		
	34	.........do.........		
	15	Quartz		
	15	Dark-green quartzite		
	22	Shale		
	27	Dark-green quartzite		
	25	.........do.........		
	40	.........do.........		
	80	Sandstone		

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
Transect 14				
18	27	Dark-green quartzite	36.0	
	34	.........do.........		
	40	Shale		
	35	Dark-green quartzite		
	37	Quartz		
	64	Dark-green quartzite		
	15	Quartz		
Transect 13				
15	40	Sandstone	35.6	
	67	Dark-green quartzite		
	18	.........do.........		
	24	Shale		
	20	Dark-green quartzite		
	39	.........do.........		
	47	Quartz		
	45	Dark-green quartzite		
	29	Quartz		
	17	Shale		
	32	Dark-green quartzite		
	33	Quartz		
	57	Dark-green quartzite		
	30	Quartz		
11, 13				Conglomerate beds 11 and 13 are too sparse to measure.
Transect 12				
9	15	Quartz	18.0	Majority of clasts <15 mm.
	15	Sandstone		
	17	Shale		
	23	.........do.........		
	20	Dark-green quartzite		
	18	Sandstone		
Transect 11				
9	34	Gray limestone	31.6	
	22	Shale		
	43	Quartz		
	22	Dark-green quartzite		
	30	Quartz		
	68	Gray limestone		
	25	Dark-green quartzite		
	30	.........do.........		
	27	Gray limestone		
	20	Dark-green quartzite		
	22	.........do.........		
	25	.........do.........		
	25	.........do.........		
	47	.........do.........		
	36	Quartz		
	30	Sandstone		
Transect 10				
7			<15	No clasts >15 mm in the top 20 cm of bed 7.
Transect 9				
7	15	Quartz	27.2	
	15	Sandstone		
	15	Shale		
	20	Quartz		
	28	Shale		
	27	Gray limestone		
	32	.........do.........		
	34	.........do.........		
	31	Dark-green quartzite		
	37	.........do.........		
	45	Shale		
	34	Dark-green quartzite		
	15	.........do.........		
	33	Shale		
Transect 8				
5	37	Sandstone	30.4	
	28	Dark-green quartzite		
	20	.........do.........		
	47	.........do.........		
	26	.........do.........		
	32	.........do.........		
	52	Shale		
	18	Quartz		
	22	.........do.........		
	22	Dark-green quartzite		
Transect 7				
3	111	Dark-green quartzite	33.8	
	42	.........do.........		
	24	.........do.........		
	28	.........do.........		
	35	.........do.........		
	30	Quartz		
	20	.........do.........		
	26	.........do.........		
	18	Sandstone		
	30	.........do.........		
	15	Dark-green quartzite		
	46	Sandstone		
	15	Quartz		
Transect 6				
3	90	Sandstone	50.0	
	69	Quartz		
	74	Sandstone		
	37	Dark-green quartzite		
	33	Quartz		
	30	Dark-green quartzite		
	62	.........do.........		
	52	Shale		
	22	Dark-green quartzite		
	58	Sandstone		
	23	Quartz		
Transect 5				
3	23	Sandstone	44.3	
	25	.........do.........		
	36	Dark-green quartzite		
	32	Sandstone		
	20	.........do.........		
	62	.........do.........		
	31	.........do.........		

Bed no.	Size (mm)	Lithology	Mean size (mm)	Comments
		Transect 5—Continued		
	52	Dark-green quartzite		
	24	.........do.........		
	112	.........do.........		
	40	.........do.........		
	15	Quartz		
	52	Dark-green quartzite		
	120	.........do.........		
	20	Quartz		
		Transect 4		
2			15	No clasts >15 mm in the top 20 cm of bed 2.
		Transect 3		
2	18	Shale	29.3	
	20	Gray limestone		
	30	.........do.........		
	15	Dark-green quartzite		
	62	Brown limestone		
	21	Sandstone		
	19	.........do.........		
	28	Brown limestone		
	17	Gray limestone		
	24	.........do.........		
	24	Dark-green quartzite		
	42	Gray limestone		
	61	.........do.........		
		Transect 2		
2	17	Sandstone	32.4	
	97	Dark-green quartzite		
	22	Black quartzite		
	36	Gray limestone		
	28	Brown limestone		
	20	Dark-green quartzite		
	15	Brown limestone		
	24	.........do.........		
	63	Gray limestone		
	20	.........do.........		
	18	Brown limestone		
	29	Gray limestone		
		Transect 1		
2	95	Sandstone	40.2	
	45	Shale		
	17	Quartz		
	22	Brown quartzite		
	44	Quartz		
	37	.........do.........		
	19	Dark-green quartzite		
	27	Brown limestone		
	19	.........do.........		
	90	.........do.........		
	20	Black quartzite		
	47	Dark-green quartzite		