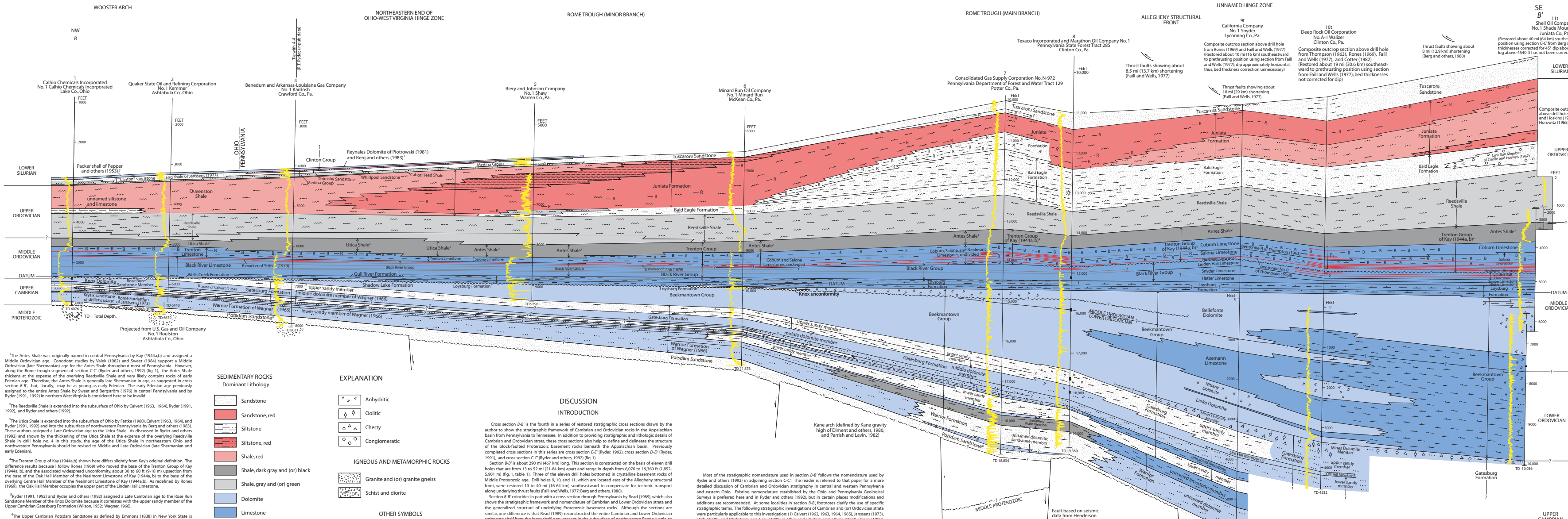
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I-2200



[1]The Antes Shale was originally named in central Pennsylvania by Kay (1944a,b) and assigned a Middle Ordovician age. Conodont studies by Valek (1982) and Sweet (1984) support a Middle Ordovician (late Shermanian) age for the Antes Shale throughout most of Pennsylvania. However, along the Rome trough segment of section *C-C'* (Ryder and others, 1992) (fig. 1), the Antes Shale thickens at the expense of the overlying Reedsville Shale and very likely contains rocks of early Edenian age. Therefore, the Antes Shale is generally late Shermanian in age, as suggested in cross section *B-B'*, but, locally, may be as young as early Edenian. The early Edenian age previously assigned to the entire Antes Shale by Sweet and Bergström (1976) in central Pennsylvania and by Ryder (1991, 1992) in northern West Virginia is considered here to be invalid.

[2]The Reedsville Shale is extended into the subsurface of Ohio by Calvert (1963, 1964), Ryder (1991, 1992), and Ryder and others (1992).

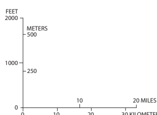
[3]The Utica Shale is extended into the subsurface of Ohio by Fettke (1960), Calvert (1963, 1964), and Ryder (1991, 1992) and into the subsurface of northwestern Pennsylvania by Berg and others (1983). These authors assigned a Late Ordovician age to the Utica Shale. As discussed in Ryder and others (1992) and shown by the thickening of the Utica Shale at the expense of the overlying Reedsville Shale in drill hole no. 4 in this study, the age of the Utica Shale in northeastern Ohio and northwestern Pennsylvania should be revised to Middle and Late Ordovician (late Shermanian and early Edenian).

[4]The Trenton Group of Kay (1944a,b) shown here differs slightly from Kay's original definition. The difference results because I follow Rones (1969) who moved the base of the Trenton Group of Kay (1944a, b), and the associated widespread unconformity, about 30 to 60 ft (9-18 m) upsection from the base of the Oak Hall Member of the Nealmont Limestone of Kay (1944a, b) to the base of the overlying Centre Hall Member of the Nealmont Limestone of Kay (1944a,b). As redefined by Rones (1969), the Oak Hall Member occupies the upper part of the Linden Hall Limestone.

[5]Ryder (1991, 1992) and Ryder and others (1992) assigned a Late Cambrian age to the Rose Run Sandstone Member of the Knox Dolomite because it correlates with the upper sandy member of the Upper Cambrian Gatesburg Formation (Wilson, 1952; Wagner, 1966).

[6]The Upper Cambrian Potsdam Sandstone as defined by Emmons (1838) in New York State is extended into northwestern and north-central Pennsylvania as the Middle and Upper Cambrian Potsdam Formation by Wagner (1966). I accept Wagner's (1966) terminology and age for this basal Cambrian sandstone in northern Pennsylvania except that the name Potsdam Sandstone is preferred instead of Potsdam Formation.

[7]On the basis of conodonts (Kleffner, 1985), the Packer shell of driller's terminology and the Reynales Dolomite of Piotrowski (1981) and Berg and others (1983) are assigned a late Early Silurian age.



EXPLANATION

SEDIMENTARY ROCKS
Dominant Lithology

- Sandstone
- Sandstone, red
- Siltstone
- Siltstone, red
- Shale, red
- Shale, dark gray and (or) black
- Shale, gray and (or) green
- Dolomite
- Limestone
- Metabentonite

Lithologic Modifiers
(Used in conjunction with Dominant Lithology)

- Sandy
- Silty
- Argillaceous, gray and (or) green
- Argillaceous, red
- Argillaceous, dark gray and (or) black
- Calcareous
- Dolomitic

- Anhydritic
- Oolitic
- Cherty
- Conglomeratic

IGNEOUS AND METAMORPHIC ROCKS

- Granite and (or) granite gneiss
- Schist and diorite

OTHER SYMBOLS

- Contact—Queried where uncertain
- Informal marker bed—Queried where uncertain
- Datum—Micritic limestone at base of Black River Limestone (Ohio), at base of Gull River Formation (northwestern Pennsylvania), and in middle of Loysburg Formation (north-central Pennsylvania)
- Unconformity—Queried where uncertain
- Cored intervals in drill holes 1, 8, and 11t
- Normal fault—Arrow shows relative movement
- Thrust faults of the Alleghanian orogeny—Postdate restored section *B-B'*
- F_1 Macrofossil-bearing interval reported in Thompson (1963)
- F_2 Macrofossil-bearing interval reported in Rones (1969)
- Gas production
- GR 0–200 Gamma-ray log for respective well—log scale generally from 0 to 200 API units

DISCUSSION

INTRODUCTION

Cross section *B-B'* is the fourth in a series of restored stratigraphic cross sections drawn by the author to show the stratigraphic framework of Cambrian and Ordovician rocks in the Appalachian basin from Pennsylvania to Tennessee. In addition to providing stratigraphic and lithologic details of Cambrian and Ordovician strata, these cross sections also help to define and delineate the structure of the block-faulted Proterozoic basement rocks beneath the Appalachian basin. Previously completed cross sections in this series are cross section *E-E'* (Ryder, 1992), cross section *D-D'* (Ryder, 1991), and cross section *C-C'* (Ryder and others, 1992) (fig. 1).

Section *B-B'* is about 290 mi (467 km) long. This section is constructed on the basis of eleven drill holes that are from 13 to 52 mi (21-84 km) apart and range in depth from 6,076 to 19,360 ft (1,852-5,901 m) (fig. 1, table 1). Three of the eleven drill holes bottomed in crystalline basement rocks of Middle Proterozoic age. Drill holes 9, 10, and 11, which are located east of the Allegheny structural front, were restored 10 to 40 mi (16-64 km) southeastward to compensate for tectonic transport along underlying thrust faults (Faill and Wells, 1977; Berg and others, 1980).

Section *B-B'* coincides in part with a cross section through Pennsylvania by Read (1989), which also shows the stratigraphic framework and nomenclature of Cambrian and Lower Ordovician strata and the generalized structure of underlying Proterozoic basement rocks. Although the sections are similar, one difference is that Read (1989) reconstructed the entire Cambrian and Lower Ordovician carbonate shelf from the inner shelf, now present in the subsurface of northwestern Pennsylvania, to the shelf margin and adjoining slope, now exposed in allochthonous terranes southwest and southeast of Harrisburg, Pa. (fig. 1). In contrast, section *B-B'* extends across the inner to middle part of the Cambrian and Lower Ordovician carbonate shelf and terminates several tens of miles southeast of the Allegheny structural front where drilled and exposed strata have experienced only a modest amount of tectonic shortening (Berg and others, 1980). Section *B-B'* also differs from Read's (1989) section in that it shows more lithologic and nomenclatural details of the Cambrian and Lower Ordovician strata and includes the entire Cambrian and Ordovician sequence.

METHODOLOGY AND STRATIGRAPHIC NOMENCLATURE

Whereas borehole geophysical logs were used to establish correlations between drilled stratigraphic units in section *B-B'*, lithologic logs, which were described largely by the Geological Sample Log Company (Pittsburgh, Pa.), were used to establish lithofacies patterns between drill holes. Correlations and lithofacies information in central Pennsylvania were supplemented locally by measured outcrop sections reported by Thompson (1963), Rones (1969), Faill and Wells (1977), and Cotter (1982). Section *B-B'* has been restored to a horizontal datum located at the base of a widespread 60- to 90-ft (18- to 27-m)-thick micritic limestone located at the base of the Gull River Formation in northwesternmost Pennsylvania, and in the middle of the Loysburg Formation in north-central and central Pennsylvania. I selected this micritic limestone as the datum horizon for section *B-B'* because it appears to be the most widespread and easily recognizable subsurface marker unit in the Cambrian and Ordovician sequence of the central Appalachian basin. Metabentonite beds in the Black River Limestone (Group) and Trenton Group are good marker units, but they cannot be traced with as much confidence as the micritic limestone unit. In addition, the shallow marine origin of the micritic limestone and its proximity to the widespread Knox unconformity, when used as datum, permits a reliable restoration of the pre-unconformity structural configuration of the block-faulted basement rocks.

Most of the stratigraphic nomenclature used in section *B-B'* follows the nomenclature used by Ryder and others (1992) in adjoining section *C-C'*. The reader is referred to that paper for a more detailed discussion of Cambrian and Ordovician stratigraphy in central and western Pennsylvania and eastern Ohio. Existing nomenclature established by the Ohio and Pennsylvania Geological Surveys is preferred here and in Ryder and others (1992), but in certain places modifications and additions are recommended. At some localities in section *B-B'*, footnotes clarify the use of specific stratigraphic terms. The following stratigraphic investigations of Cambrian and (or) Ordovician strata were particularly applicable to this investigation: (1) Calvert (1962, 1963, 1964, 1965), Janssens (1973), Stith (1979), and Wickstrom and Gray (1988) in Ohio and (2) Berg and others (1983), Rones (1969), Thompson (1963), and Wagner (1966, 1976) in Pennsylvania.

The correlation chart (fig. 2) shows the chronostratigraphic position of Cambrian and Ordovician units identified in selected tectonic provinces along section B-B' and summarizes the nomenclature assigned to them. Moreover, this chart compares the nomenclature and chronostratigraphic position of Cambrian and Ordovician units with those in the adjoining Lebanon Valley allochthon and Reading Prong (Berg and others, 1983; MacLachlan and Root, 1966).

European chronostratigraphic units (for example, Tremadocian through Ashgillian Stages) commonly do not apply to the cratonal and platformal Ordovician rocks of North America (Ross and others, 1984). Therefore, in this paper I apply North American chronostratigraphic units used by Barnes and others (1981) and Ross and others (1982) rather than the European chronostratigraphic units used by Palmer (1983), Berg and others (1983), and the Correlation of Stratigraphic Units of North America (COSUNA) charts (for example, see Patchen and others, 1984). My correlation chart (fig. 2) subdivides the Ordovician System into the Lower, Middle, and Upper North American Series of Barnes and others (1981) and equates the Ibexian, Whiterockian and Mohawkian combined, and Cincinnatian Series of Ross and others (1982), respectively. In addition, because of its well-established usage in North America, the Canadian Series of Barnes and others (1981) is shown as being equivalent to the Ibexian Series of Ross and others (1982). By equating the Ibexian (Canadian) Series with the Lower Ordovician Series, both the Whiterockian and Mohawkian Series with the Middle Ordovician Series, and the Cincinnatian Series with the Upper Ordovician Series, I am in agreement with many Ordovician specialists in North America such as Miller (1984), Repetski (1985), Sweet and Bergström (1986), and Shaw and others (1990).

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

BASEMENT STRUCTURE

Details of the structural configuration of block-faulted Middle Proterozoic basement rocks underlying the Appalachian basin in Pennsylvania are poorly understood because (1) few drill holes have penetrated the sedimentary cover, (2) magnetic and gravity data have not been calibrated to known basement rock types and structures, and (3) very few seismic profiles have been published. Most interpretations show the northeast-trending, fault-controlled Rome trough as the dominant tectonic element of basement structure in Pennsylvania (Wagner, 1976; Harris, 1978; Beardsley and Cable, 1983; Harper, 1989; Read, 1989; Ryder and others, 1992). The Rome trough also is recognized in this report, but here it consists of several moderate- to low-relief grabens and intervening horsts. The basement-involved normal faults and adjoining fault blocks interpreted by me on section *B-B'* are based on published seismic lines (Beardsley and Cable, 1983; Henderson and Timm, 1985), gravity data (Diment and others, 1980; Parish and Lavin, 1982), and thickness changes in drilled Cambrian and Ordovician strata. Because the basement faults underlying section *B-B'* are based on limited data, and thus are highly conjectural, they are shown on figure 1 as 50- to 150-mi (80- to 240-km)-long, incomplete line segments. From northwest to southeast, I suggest that the following basement-involved structures are crossed by section *B-B'*: (1) the Wooster arch of Coogan and Maki (1988); (2) the northeastern end of the Ohio-West Virginia hinge zone of Ryder (1991, 1992) and Ryder and others (1992); (3) the minor branch of the Rome trough; (4) the Kane arch (named here) that is defined by the Kane gravity high of Diment and others (1980) and Parrish and Lavin (1982) and was interpreted as a positive basement block by Parrish and Lavin (1982) and Harper (1989); (5) the main branch of the Rome trough (the Olin basin of Wagner, 1976); (6) the Northeastern Pennsylvania arch (named here) that borders the northwestern flank of the Scranton gravity high of Diment and others (1972); and (7) a major unnamed hinge zone that overlaps the southeastern margin of the Northeastern Pennsylvania arch along which Middle Proterozoic basement has been downdropped and estimated 500 to 1,500 ft (152-457 m) along one or more down-to-southeast normal faults (fig. 1).

A 15- to 30-mi (24- to 48-km)-wide, northeast-trending low intensity magnetic anomaly recognized by Zietz and others (1980) and Culotta and others (1990) coincides with a large part of the minor branch of the Rome trough. Culotta and others (1990) suggested that this low intensity magnetic anomaly, a part of their Amish anomaly, marks a suture zone in the Grenville orogenic belt.

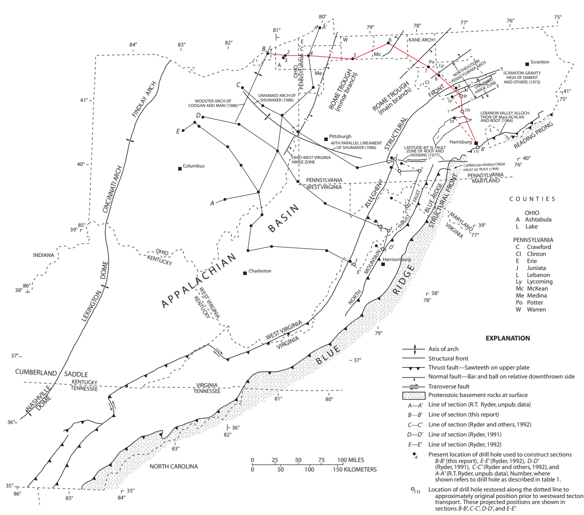


Figure 1.—Map of Pennsylvania, Ohio, and adjoining States showing the location of section *B-B'* and selected tectonic features.

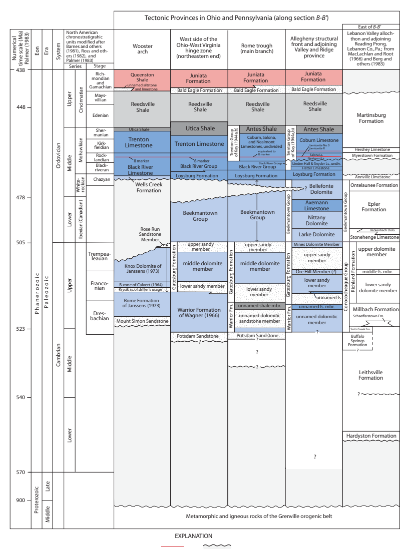


Figure 2.—Correlation chart of Proterozoic, Cambrian, and Ordovician rocks along section *B-B'* and in the adjoining Lebanon Valley allochthon and Reading Prong of Lebanon County, Pennsylvania. Absolute age (in Ma) is taken from the Geological Time Scale compiled by Palmer (1983). The time scale is nonlinear. North American chronostratigraphic units are modified after Barnes and others (1981), Ross and others (1982), and Palmer (1983).

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Table 1. - Descriptions of drill holes used to construct section *B-B'*

Number	Name	Location	Permit number	Lithologic log	Cored intervals (formation)	Total depth (ft)	Ages of oldest rocks drilled (formation)
1	Calhio Chemicals Incorporated No. 1 Calhio Chemicals Incorporated	Perry Township, Lake County, Ohio	142	Yes[1]	5,357-5,417 ft (Wells Creek Formation and Knox Dolomite) 6,065-6,076 ft (Middle Proterozoic basement rocks)	6,076	Middle Proterozoic.
2	Quaker State Oil and Refining Corporation No. 1 Kemmer	Jefferson Township, Ashtabula County, Ohio	213	Yes[1]		6,440	Late Cambrian (Rome Formation of Janssens, 1973).
3	U.S. Gas and Oil Company No. 1 Roulston	Morgan Township, Ashtabula County, Ohio	286	Yes[1]		6,670	Middle Proterozoic.
4	Benedum and Arkansas-Louisiana Gas Company No.1 Kardosh	Linesville quadrangle, Crawford County, Pa.	20007	Yes[1]		8,031	Middle Proterozoic.
5	Biery and Johnson Company No. 1 Shaw	Cobham quadrangle, Warren County, Pa.	281	Yes[1]		9,398	Late Cambrian (Gatesburg Formation).
6	Minard Run Oil Company No. 1 Minard Run	Derrick City quadrangle, McKean County, Pa.	2529	Yes[1]		11,878	Middle and Late Cambrian (Potsdam Sandstone of Wagner, 1966).
7	Consolidated Gas Supply Corporation No. N-972 Pennsylvania Department of Forest and Water Tract 129	Tamarack quadrangle, Potter County, Pa.	182	Yes[1]		18,834	Middle and Late Cambrian (Potsdam Sandstone of Wagner, 1966).
8	Texaco Incorporated and Marathon Oil Company No. 1 Pennsylvania State Forest Tract 285	Glen Union quadrangle, Clinton County, Pa.	20276	Yes[1]	15,084-15,143 ft (Black River Group) 15,883-15,942 ft (Beekmantown Group) 17,600-17,620 ft 17,620-17,650 ft 17,965-17,999 ft (Gatesburg Formation)	19,360	Middle and Late Cambrian (Warrior Formation).
9	California Company No. 1 Snyder	Linden quadrangle, Lycoming County, Pa.	S-1	Yes[1, 2]		5,808	Middle and Late Cambrian (Warrior Formation).
10	Deep Rock Oil Corporation No. A-1 Walizer	Loganton quadrangle, Clinton County, Pa.	S-1	Yes[1, 2]		4,532	Late Cambrian (Gatesburg Formation).
11	Shell Oil Company No. 1 Shade Mountain	McClure quadrangle, Juniata County, Pa.	1	Yes[1]	7,550-7,560 ft (Beekmantown Group) 10,010-10,036 ft (Gatesburg Formation)	10,036	Late Cambrian (Gatesburg Formation).

Sources of lithologic logs:
[1] Geological Sample Log Company, Pittsburg, PA 15234.
[2] Wagner (1966).

STRATIGRAPHIC FRAMEWORK OF CAMBRIAN AND ORDOVICIAN ROCKS IN THE CENTRAL APPALACHIAN BASIN FROM LAKE COUNTY, OHIO, TO JUNIATA COUNTY, PENNSYLVANIA

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2002