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AN ASSESSMENT OF THE LITHOSTRATIGRAPHIC AND INTERPRETIVE VALUE OF THE TRADITIONAL "BIOSTRATIGRAPHY" OF THE TYPE UPPER ORDOVICIAN OF NORTH AMERICA

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ABSTRACT. The type Upper Ordovician of North America was originally subdivided into formations and members prior to 1910. Although the original formation names have since been used for various purposes, their mappability and interpretive value has not been properly evaluated. Since the advent of the 1961 Stratigraphic Code, some Ordovician stratigraphers have concluded incorrectly that these formations are entirely *biostratigraphic* in nature and therefore unsuitable for modern lithostratigraphic usage. However, some of the supposedly "biostratigraphic" units were originally defined as biofacies having distinctive lithologic identities. These units are easy to recognize in outcrop, are thin enough to permit detailed subdivision of the stratigraphic column, and are laterally persistent throughout the study area. Furthermore, the traditional names have priority and have never been formally abandoned or replaced with alternative names. Most importantly, each formation corresponds to a distinct lithotope, making it valuable for paleoenvironmental interpretation. Accordingly, the following biofacies are recognized as true rock-stratigraphic units and are redefined in accordance with the rules of the 1983 North American Stratigraphic Code: the Corryville, Mt. Auburn, Sunset, Oregonia, Waynesville, Liberty, Whitewater, and Saluda Formations in southwestern Ohio and the Whitewater and Saluda Formations in southeastern Indiana.

INTRODUCTION AND HISTORICAL DEVELOPMENT

The Cincinnatian Series (Upper Ordovician) is a structurally undeformed sequence of interbedded limestones and shales exposed in southwestern Ohio, southeastern Indiana, and northern Kentucky (fig. 1). The supposedly "monotonous" interbedding of limestone and shale in the Cincinnatian Series, combined with an abundant and well-preserved fauna, led the earliest workers to believe that stratigraphic subdivisions of these rocks should be based mostly on faunal rather than lithologic characteristics. Moreover, the early workers were largely stratigraphic "lumpers." Riddell's "Blue Miami Limestone" (1837), Briggs' "Great Limestone Deposite" (1838), and Orton's (1873) stratigraphic subdivision of "River

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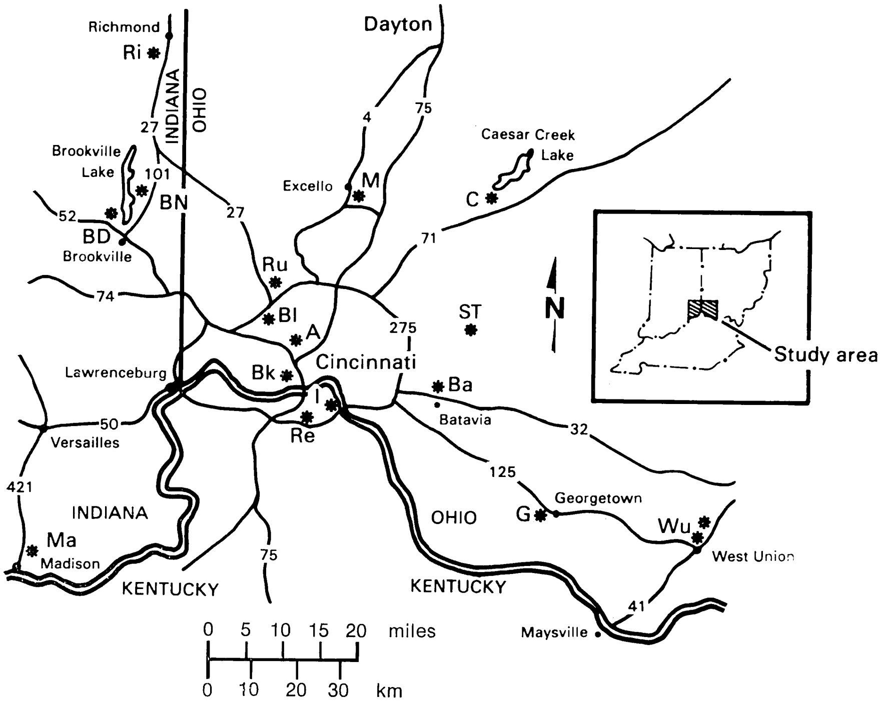


Fig. 1. Outcrop locations in study area. Full locality names and exact locations are given in app. 2.

Quarry Beds," "Middle Eden Shales," "Hill Quarry Beds," and "Lebanon Beds" are all examples of the tendency to define broad, undifferentiated stratigraphic units. With time, additional subdivisions, based on rock and fossil properties, were described and refined. The development of this subdivision took place mainly between 1902 and 1940 and can be credited to the pioneering efforts of J. M. Nickles, A. F. Foerste, R. S. Bassler, E. R. Cumings, E. O. Ulrich, and many others. The most commonly cited compilation of this partly biostratigraphic classification is that of Caster, Dalvé, and Pope (1955), in which 8 formations and 14 members are described. Excellent summaries of the development of Cincinnatian stratigraphy are given by Cumings (1922), Gutstadt (1958), and Weiss and Norman (1960).

Perhaps the first worker to recognize the need to distinguish between rock-defined and fossil-defined Cincinnatian stratigraphy was Gutstadt (1958). His study was published just 3 yrs prior to the first appearance of the Code of the American Commission on Stratigraphic Nomenclature, which recommended that rock stratigraphic units be defined on the basis of lithologic characteristics. The Code provided the impetus for a number of lithostratigraphic studies of the Cincinnatian, starting in 1964 (fig. 2).

Cincinnatian lithostratigraphy has been defined formally in southeastern Indiana (Brown and Lineback, 1966; Hatfield, 1968) and in the Maysville, Kentucky area (Peck, 1966). Recently, the U.S. Geological Survey, in cooperation with the Kentucky Geological Survey, concluded a geologic mapping project in central and north-central Kentucky which recognized lithostratigraphic units defined by Weir and Greene (1965), Weir, Greene, and Simmons (1965), Peck (1966), and others (see Pojeta, 1979, for a summary of this work). In addition, Weiss and others (1972) mapped the Grant Lake, Bull Fork, and Drakes formations (from Peck, 1966) in a small portion of Adams and Brown counties in Ohio (the Maysville East Quadrangle). Ford (1967) formally redefined the lower part of the Cincinnatian Series in southwestern Ohio. Ford (1967) assigned the lowermost Cincinnatian to the Kope, Fairview, Miamitown, and Bellevue formations in the Cincinnati area but chose to leave the strata above the Bellevue Limestone as "Unnamed Beds" (fig. 2).

Subsequent workers have referred to supra-Bellevue strata in Ohio as "Unnamed Beds," following Ford's (1967) designation or in one of several alternative ways. As a result, considerable confusion exists in naming and correlating stratigraphic intervals of Late Ordovician age in Ohio. In some cases, formal lithostratigraphic names established in nearby

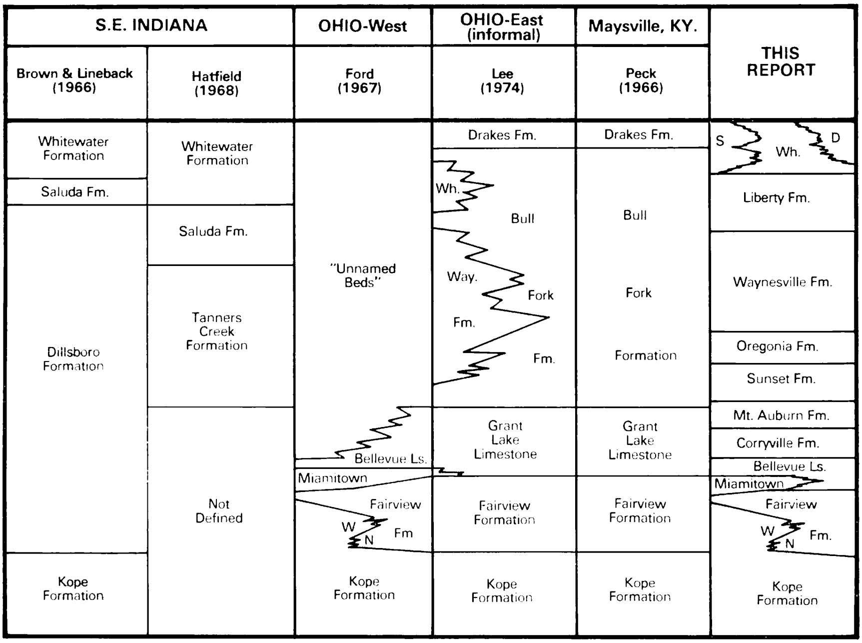


Fig. 2. Selected examples of Cincinnatian Series stratigraphic nomenclature. Kope Formation was originally defined by Weiss and Sweet (1964). In Ford (1967) column, "W" refers to the Wessleman Tongue and "N" refers to the North Bend Tongue. In last column, "S" = Saluda Formation, "Wh." = Whitewater Formation, and "D" = Drakes Formation. Lateral correlations are approximate.

states have been used in Ohio. For example, Pojeta (1979, fig. 2) used the name "Bull Fork Formation," a unit established in Kentucky, to replace Ford's (1967) "Unnamed Beds" at Cincinnati, Ohio. Similarly, Richards (1972) referred to strata exposed near Waynesville, Ohio as the "Tanner's Creek Formation," a unit established in southeastern Indiana. Other workers have utilized the traditional "biostratigraphic" taxonomy (for example, Osgood, 1970; Martin, 1975; Hinterlong, ms). In some cases the traditional names were used but were referred to in an *informal* sense (for example, Alexander, 1975; Meyer and others, 1981; Schumacher, ms). Others have used a combination of lithostratigraphic names borrowed from nearby states and the traditional "biostratigraphic" names established in Ohio. For example, Schumacher and Ausich (1983) referred to strata exposed in a reservoir spillway in Warren County, Ohio as the Bull Fork Formation. However, ". . . for a more exact placement of [Echinoderm sites in] the spillway section" the traditional "biostratigraphic" names were used (p. 61 and fig. 3). Similarly, Harris and Martin (1979) used a combination of lithostratigraphic and "biostratigraphic" names for strata exposed near Brookville, Ind. Such usage indicates that the thick, undifferentiated lithostratigraphic units defined in Kentucky and Indiana are unsuitable for exact placement and correlation of thin stratigraphic intervals in Ohio.

Clearly, using several names to describe the same stratigraphic interval is both undesirable and confusing. This paper dispels some of the confusion that exists about the traditional stratigraphic taxonomy of the type Cincinnatian of North America. In addition, it describes the usefulness of the traditional stratigraphic units for depositional interpretation, detailed stratigraphic subdivision, and mapping purposes. The study also provides a model for the stratigraphic subdivision of mixed carbonate-clastic sequences.

ASSESSMENT OF TRADITIONAL "BIOSTRATIGRAPHY"

The preceding discussion illustrates the lack of uniformity in naming stratigraphic intervals of Cincinnatian age in Ohio. Since the advent of the 1961 Stratigraphic Code, numerous workers have assumed that the traditional stratigraphic nomenclature developed in the early 1900's is entirely biostratigraphic in nature and therefore unsuitable for lithostratigraphic usage. Examples include Brown and Lineback (1966, p. 1018-1019), Ford (1967, p. 918, 934, and fig. 2), Harris and Martin (1979, p. 1296), Tobin (ms, 1980, p. 5), Meyer and others (1981, p. 32), and Schumacher and Ausich (1983, p. 61).

This incorrect conclusion is based largely on quotations from summary articles such as Cumings (1908 and 1922) and Gutstadt (1958), without consulting the *original* references (for example, Nickles, 1902 and 1903; Foerste, 1903 and 1910; Bassler, 1906). The most commonly cited historical review (Gutstadt, 1958) is based on a previous historical summary (Cumings, 1922) in which the author asserts that the traditional Cincinnatian formations are actually biostratigraphic zones without actually proving it by quoting the original descriptions. However, reference

Formation		Author	Original Type Section or Area	Reference Section	Maximum Thickness	Bedding Style	Bedding Thickness	Shale Content	Dominant Limestone(s)	Dominant Shale Type
SALUDA	Upper Member	Foerste (1903)	Saluda Creek, Indiana	Madison, Indiana	3.3 meters (11 ft)	Wavy very discontinuous	Thin, 2 cm	0%	dolomudstones	N/A
SALUDA	Middle Member	Foerste (1903)	Saluda Creek, Indiana	Madison, Indiana	13 meters (43 ft)	Massive	N/A	0%	sucrosic dolostones	N/A
SALUDA	Lower Member	Foerste (1903)	Saluda Creek, Indiana	Madison, Indiana	10.1 meters (33 ft)	Planar discontinuous	Medium-thick ls ≈ 12 cm sh ≈ 4 cm	27%	dolomitic wackestones and mudstones	dolomitic claystone
Whitewater		Nickles (1903)	Whitewater River Richmond Indiana	Caesar Creek Dam	10.8 meters (35 ft)	Wavy discontinuous	Thin ls ≈ 4 cm sh ≈ 2 cm	14%	grainstones	claystone
Liberty		Nickles (1903)	Liberty Indiana	Caesar Creek Dam	18.3 meters (60 ft)	Planar moderately continuous	Thick ls ≈ 8 cm sh ≈ 8 cm	45%	packstones and grainstones	dolomitic mudstone
Waynesville		Nickles (1903)	Waynesville, Ohio	Caesar Creek Dam	37.3 meters (122 ft)	Planar moderately continuous	Thick ls ≈ 5 cm sh ≈ 11 cm	67%	packstones and wackestones	dolomitic mudstone
Oregonia		Nickles (1902) Foerste (1910)	Oregonia, Ohio	Caesar Creek Dam, Aiken High School	7.3 meters (24 ft)	Nodular, very discontinuous	Thin ls ≈ 4 cm sh ≈ 4 cm	44%	grainstones	mudstone
Sunset		Nickles (1902) Foerste (1910)	Sunset, Kentucky	Aiken High School	13.5 meters (44 ft)	Planar moderately continuous	Medium ls ≈ 6 cm sh ≈ 8 cm	52%	packstones and wackestones	mudstone
Mt. Auburn		Nickles (1902)	Mt Auburn area, Cincinnati	Rumpke Land Fill, Blue Rock Road, Middletown	5.1 meters (17 ft)	Nodular, very discontinuous	Thin ls ≈ 4 cm sh ≈ 2 cm	37%	argillaceous packstones and grainstones	dolomitic claystone
Corryville		Nickles (1902)	Corryville, Price Hill, and Fairview Heights in Cincinnati	Stonelick Creek	32 meters (105 ft)	Planar, moderately continuous	Thick ls ≈ 5 cm sh ≈ 10 cm	64%	packstones	dolomitic mudstone

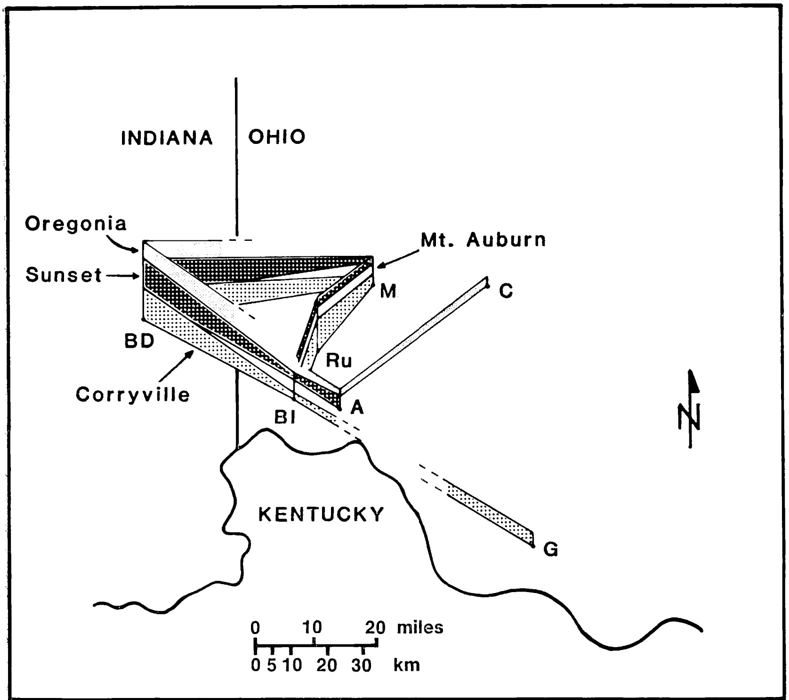
Fig. 3. Lithologic descriptions of redefined Cincinnatian formations.

to the orginal descriptions shows that most of the traditional "biostratigraphic" units were defined on the basis of rock and fossil properties. For example, the "Corryville or *Chiloporella nicholsoni* Beds" were originally described by Nickles (1902, p. 83) as follows: "In this division the limestones are thinner and less frequent than in the quarry beds [Fairview and Bellevue] and the shales more yellowish. Blue shale also occurs." Although Nickles' terminology is outdated, he has adequately described a shale-rich facies containing widely spaced ("less frequent") limestone interbeds which are thinner than those found in the Fairview Formation. Such a description is adequate for distinguishing this facies from the underlying thin-bedded, shale-poor "Bellevue Beds" and from the overlying nodular-bedded "Mt. Auburn Beds."

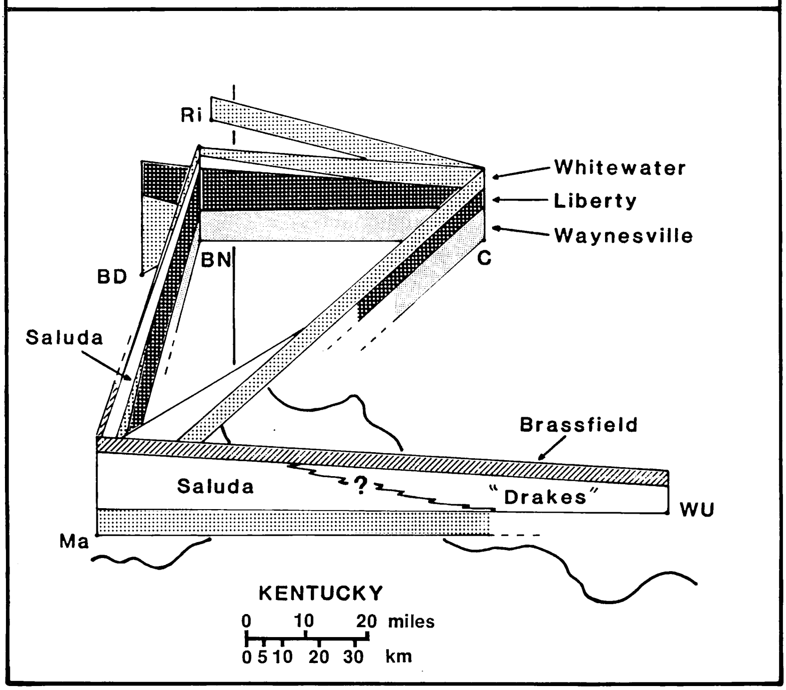
Similarly, the Sunset Formation and the Oregonia Formation were originally described in a lithologic sense. Nickles (1902) originally used the name "Warren or *Homotrypa bassleri* Beds" (after Warren County, Ohio) to describe the interbedded limestones and shales that lie above the "Mt. Auburn Beds." Nickles (1902, p. 86) described the lower part of the "Warren Beds" as follows: "Limestone is not very abundant in the beds under consideration, whose thickness is about 80 feet. The intercalated shales are of a dark bluish color, rather marly." Nickles (1902, p. 86) also noted that, "Toward the top of this division, the layers, both limestone and shale, especially the latter, become rough and nodular, indicating a marked change in the sedimentation." The planar-bedded facies at the base of the Warren Beds corresponds to the Sunset Formation, and the nodular-bedded facies at the top corresponds to the Oregonia Formation (as defined in this report). The term "Warren Beds" was later replaced by the name "Arnheim Bed" after the town of Arnheim, in Brown County, Ohio (Foerste, 1905). Foerste also noticed the lithologic distinction between the planar-bedded facies below and the nodular-bedded facies above. Accordingly, Foerste (1910) subdivided the Arnheim into two divisions, the lower "Sunset Division" (after Sunset, Ky.) and the upper "Oregonia Division" (after Oregonia, Ohio).

In addition to the traditional units redefined by Ford (1967), the following stratigraphic units were first defined on the basis of rock and fossil properties: the Corryville, Mt. Auburn, Sunset, and Oregonia members and the Waynesville, Liberty, Whitewater, and Saluda formations. The original descriptions of all these units are included in the text of this report and are summarized in figure 3. Although the original lithologic descriptions of these units are unsophisticated by modern standards, they are adequate for distinguishing rock facies in the field. Furthermore, the geologists who first described these facies unknowingly adhered to most of the rules for establishing rock-stratigraphic units as outlined by the 1983 North American Stratigraphic Code. Each formation was described in a recognized scientific medium in which the following information was included: statement of intention to designate a formal unit, selection of a name, historical background, definition of the unit in its type area, distinguishing characteristics, dimensions and shape, and geologic age and correlation. The only variance from the modern rules was that formational contacts were defined by the vertical ranges of fossil species. However, in most cases, fossil distributions are facies controlled. As a result, faunally defined boundaries closely correspond to changes in lithology.

Accordingly, these supposedly "biostratigraphic" units are herein recognized as true rock facies, and it is recommended that they be utilized for future stratigraphic work in Ohio. These rock facies are easy to recognize in the field and are thin enough to permit a more detailed subdivision of the stratigraphic column than the thick, undifferentiated formations more recently described in Kentucky and Indiana. Because these facies are laterally persistent throughout the study area, they should also be useful as mapping units (fig. 4). Mappability of the traditional stratigraphy is presently being tested in southwestern Ohio by the Ohio Division of Geological Survey (Schumacher, 1985, personal commun.). The traditional stratigraphic names also have priority (1983 Stratigraphic Code, art. 7) and have been used to denote rock facies for nearly 60 yrs, even after the introduction of lithostratigraphic taxonomy in Kentucky and Indiana nearly 20 yrs ago. Most importantly, these traditional names have never been formally abandoned or replaced with alternative names, although informal suggestions have been made (Lee, ms; Hay, ms).



A.



B.

Fig. 4. Fence diagram of study area, showing regional correlation of formations redefined in this report. A = Corryville to Oregonia sequence; B = Waynesville to Saluda sequence.

REDEFINED STRATIGRAPHIC UNITS

The following traditional names are herein formally redefined as rock-stratigraphic units having formational status: Corryville, Mt. Auburn, Sunset, Oregonia, Waynesville, Liberty, Whitewater, and Saluda (fig. 2). Each unit possesses a high degree of lithologic homogeneity which distinguishes it from contiguous units. Rock properties that are the most useful for distinguishing these formations include shale content (expressed as percent of total thickness), dominant limestone rock types (after Dunham, 1962), and bedding style, thickness, and lateral continuity (fig. 3). The two most commonly cited bedding thickness classifications (McKee and Weir, 1953; Ingram, 1954) are not subdivided adequately in the 1 to 20 cm thickness range to distinguish relative differences in bedding thickness for each formation. Therefore, an original bedding thickness classification scheme is used in this report (fig. 5). The upper and lower boundaries of these formations were placed originally at the contacts of the faunas that characterized each lithofacies. Accordingly, upper and lower contacts are herein redefined lithologically to conform to article 23 of the 1983 Stratigraphic Code. For consistent usage of terms, the Corryville, Mt. Auburn, Sunset, and Oregonia members are elevated to formational status. The formations to which they were originally assigned (McMillan and Arnheim) contain within their boundaries several distinctively different lithofacies and therefore do not possess the necessary degree of lithologic homogeneity for them to be considered as formations. Consequently, the McMillan and Arnheim formations are abandoned (1983 Stratigraphic Code, art. 24b).

In the following subsections, each of the redefined Cincinnatian formations is described in detail. Specific outcrop locations studied in the

STRATIFICATION TYPE	THICKNESS
Very Thick Bedded	⩾10 cm
Thick Bedded	⩾8 cm, but <10 cm
Medium Bedded	⩾5 cm, but <8 cm
Very Thin Bedded	>2 cm, but <5 cm
Thin Bedded	1–2 cm
Laminated	<1 cm

Fig. 5. Bedding thickness classification for type Cincinnatian strata.

field area are given in figure 1 and app. 2. Geologic and stratigraphic descriptions of each outcrop are given in figures 6, 7, 8, and 9 and app. 1. An updated lithologic and paleontologic description of the formations recognized by Ford (1967) may also be found in Tobin (ms, 1982, p. 166-176).

Corryville Formation.—The lithology of the "Corryville Beds" was first described by Nickles (1902, p. 83, 98) from exposures in the Corryville, Price Hill, and Fairview Heights neighborhoods of Cincinnati. Nickles' description is quoted and discussed in the previous section of this report and is not repeated here. Bassler (1906, p. 10) later ranked the Corryville as a member of his "McMillan Formation," named after McMillan Avenue in Cincinnati. The "McMillan Formation" was later rejected as a lithostratigraphic unit by Ford (1967, p. 934) and Peck (1966, p. B8). In this report, the "McMillan Formation" is also considered to be inadequate as a lithostratigraphic unit for two reasons: (1) it was not described lithologically by Bassler (1906), and (2) it contains within its boundaries three different rock facies and is therefore too heterogeneous to be considered a valid formation (1983 Stratigraphic Code, art. 24b). Accordingly, the "McMillan Formation" is herein abandoned, and the Corryville "Member" is elevated to formational status.

The Corryville Formation is completely exposed at the Stonelick Creek locality, where it is approx 32 m thick (Meyer and others, 1981, fig. 34, 35; and fig. 1, this report). This outcrop has been described in detail by Hinterlong (ms) and Schumacher (ms) and is well known among Upper Ordovician stratigraphers. Accordingly, the Stonelick Creek section is designated as the principal reference section of the Corryville Formation (app. 2). Three additional exposures in Ohio include the Middletown, Rumpke Landfill, and Blue Rock Road localities (fig. 1 and app. 2). The Corryville Formation crops out as far east as Georgetown, Ohio, as far west as Brookville, Ind., and as far north as Middletown, Ohio (fig. 1). The Corryville Formation is correlatable with part of the Dillsboro Formation of Indiana and with the middle part of the Grant Lake Limestone of Kentucky (fig. 2).

The Corryville Formation is a thick-bedded (8 cm overall), shale-rich (64 percent) facies composed of medium (5 cm), widely spaced, planar-bedded limestones and very thick (10 cm), flaggy shale interbeds. Bedding is laterally continuous, relative to the other formations. Sixty-five percent of the limestones in the Corryville Formation are mud-rich packstones and wackestones containing a diverse, thin-shelled, open-marine fauna. Grainstones (20 percent), siltstones (13 percent), and mudstones (2 percent) are also present. Most shale beds are composed of dolomitic mudstone. Body fossils include bryozoans, brachiopods, trilobites, crinoids, edrioasteroids, gastropods, pelecypods, ostracods, and conodonts. Trace fossils include *Chondrites, Trichophycus, Paleophycus, Diplocraterion,* unidentified vertical tubes, and gastropod trails. Sedimentary structures include symmetric and asymmetric ripples, planar and cross lamination, tool marks, flute marks, gutter casts, rare ball and pillow structures, imbricated brachiopod shells, and current-oriented cephalopods.

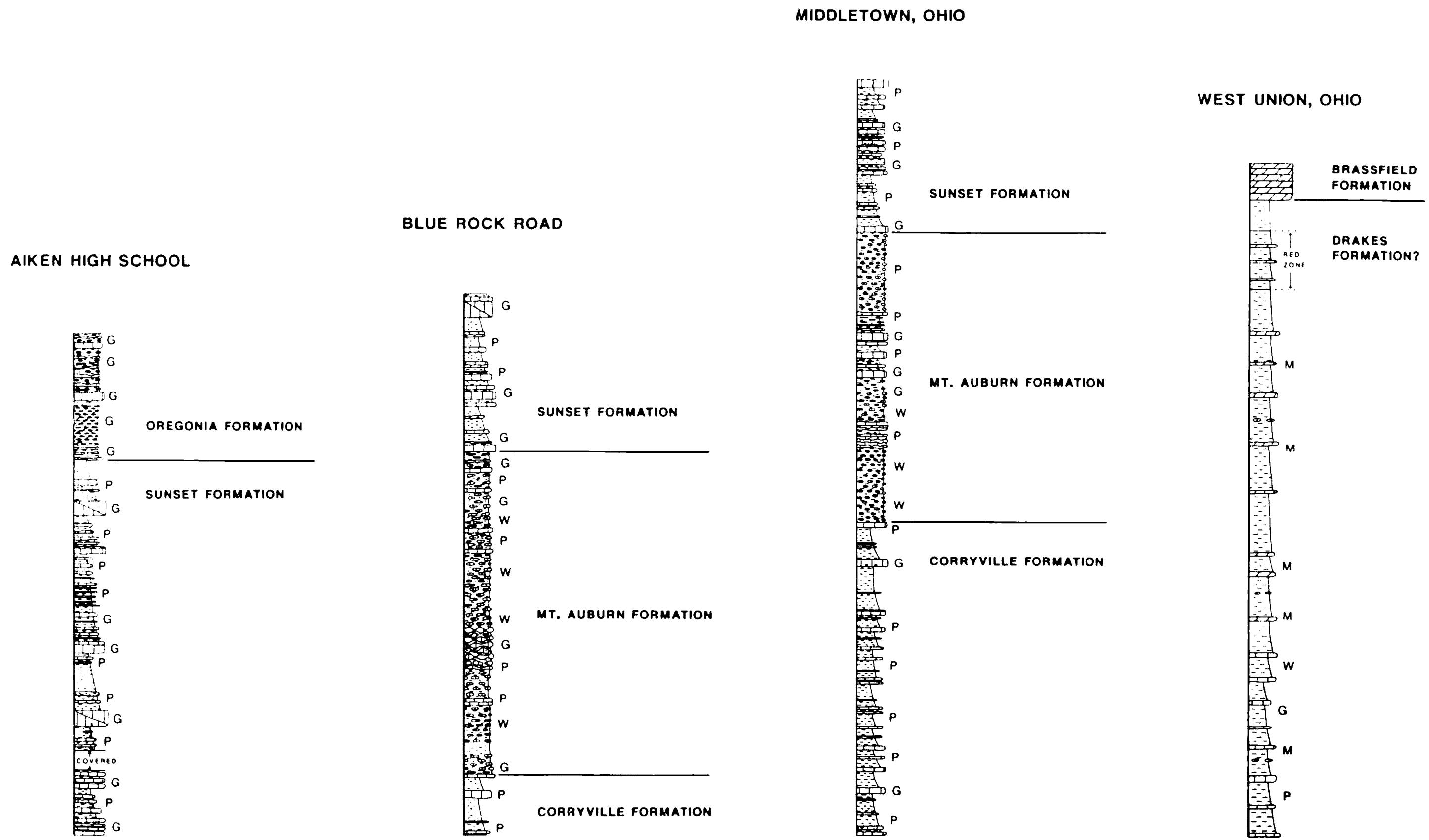


Fig. 6. Weathering profiles of selected Cincinnatian outcrops in Ohio. Limestone rock types are abbreviated as follows: G (grainstone), P (packstone), W (wackestone), M (mudstone).

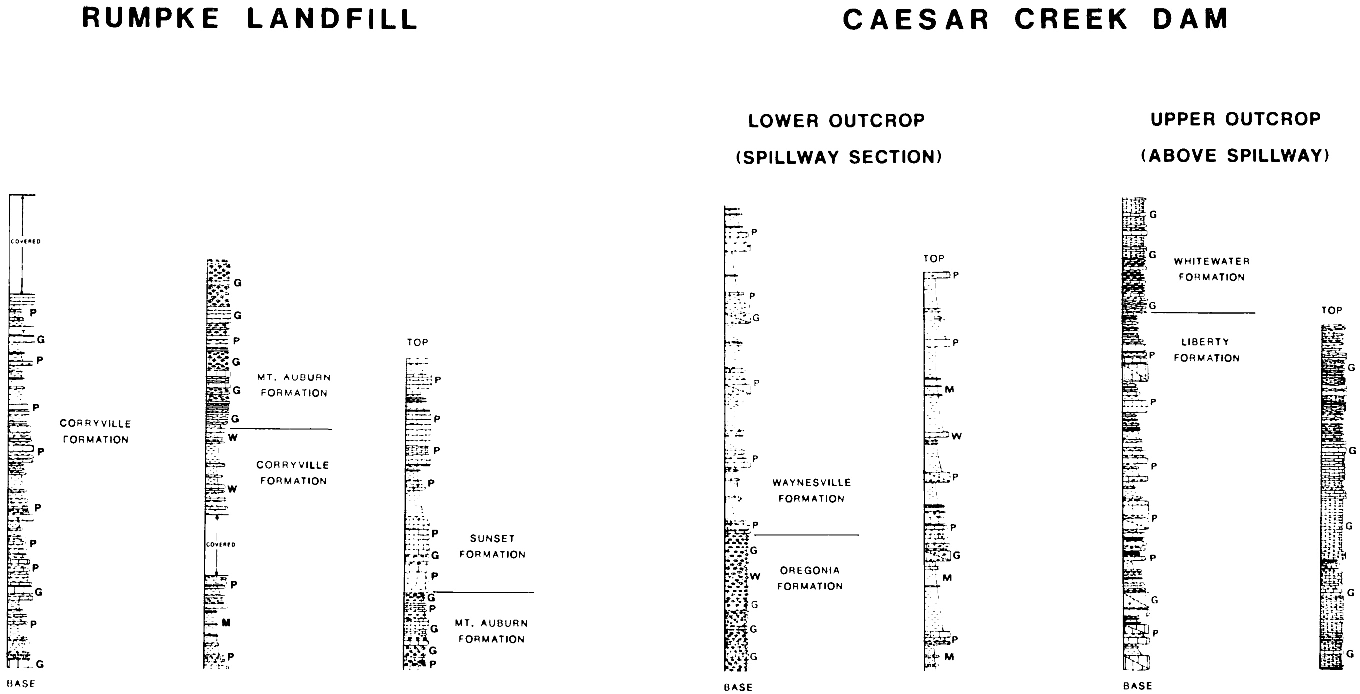


Fig. 7. Weathering profiles of the Rumpke Landfill and Caesar Creek Dam outcrops in Ohio. Limestone rock types are abbreviated as follows: G (grainstone), P (packstone), W (wackestone), M (mudstone).

The upper and lower contacts of the Corryville Formation were defined originally by the vertical range of the bryozoan *Chiloporella nicholsoni* (Nickles, 1902). In accordance with Article 23 of the 1983 Stratigraphic Code, these contacts are herein redefined lithologically. The lower contact is placed at the top of the uppermost wavy or nodular-bedded, shelly limestone of the Bellevue Limestone, which is usually overlain by a shale bed ranging in thickness from 5 to 10 cm. This contact is well exposed at the Georgetown and Stonelick Creek localities (fig. 1). The base of the Corryville Formation is sometimes marked by a 1 to 2-foot thick zone of gradation containing planar, wavy, and nodular limestone beds and thin shale beds. In such cases, the lower contact is placed at the base of the zone of gradation.

The upper contact with the overlying Mt. Auburn Formation is redefined as the top of the highest planar limestone bed that underlies the lowest nodular or wavy-bedded interval. This contact is well exposed at the Blue Rock Road, Rumpke Landfill, and Middletown localities (figs. 1, 6, and 7). The overlying Mt. Auburn Formation pinches out between Cincinnati, Ohio and Brookville, Ind. (fig. 4). Therefore, the Mt. Auburn Formation may be absent in the westernmost part of southwestern Ohio. Although this has not been observed in outcrop, provisions are made herein for redefining the upper contact of the Corryville Formation, based on the rock record at the Brookville Dam locality. Accordingly, in the absence of the Mt. Auburn Formation in Ohio, the top of the Corryville Formation is redefined as the base of a planar limestone bed that overlies the highest shale bed greater than 0.5 m in thickness. This

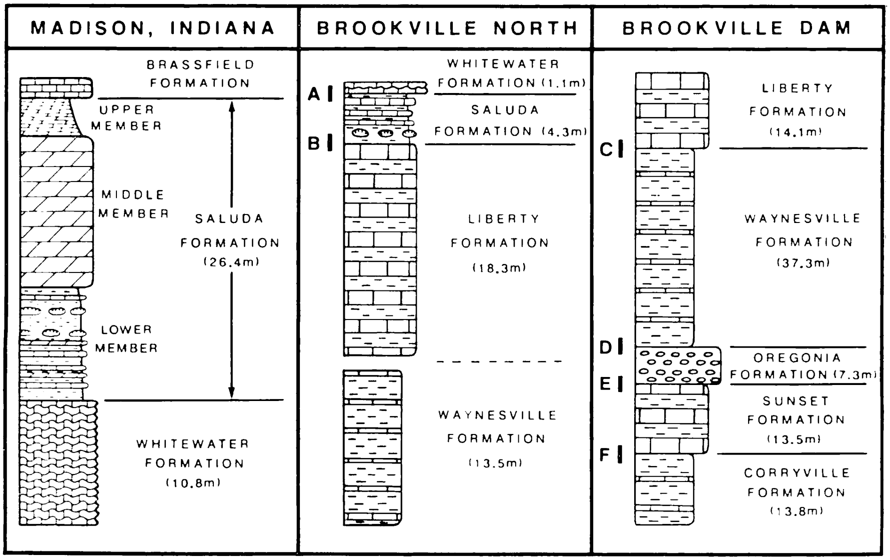


Fig. 8. Vertical profiles of three outcrops described in southeast Indiana. Details of formational contacts (A through F) are given in figure 9.

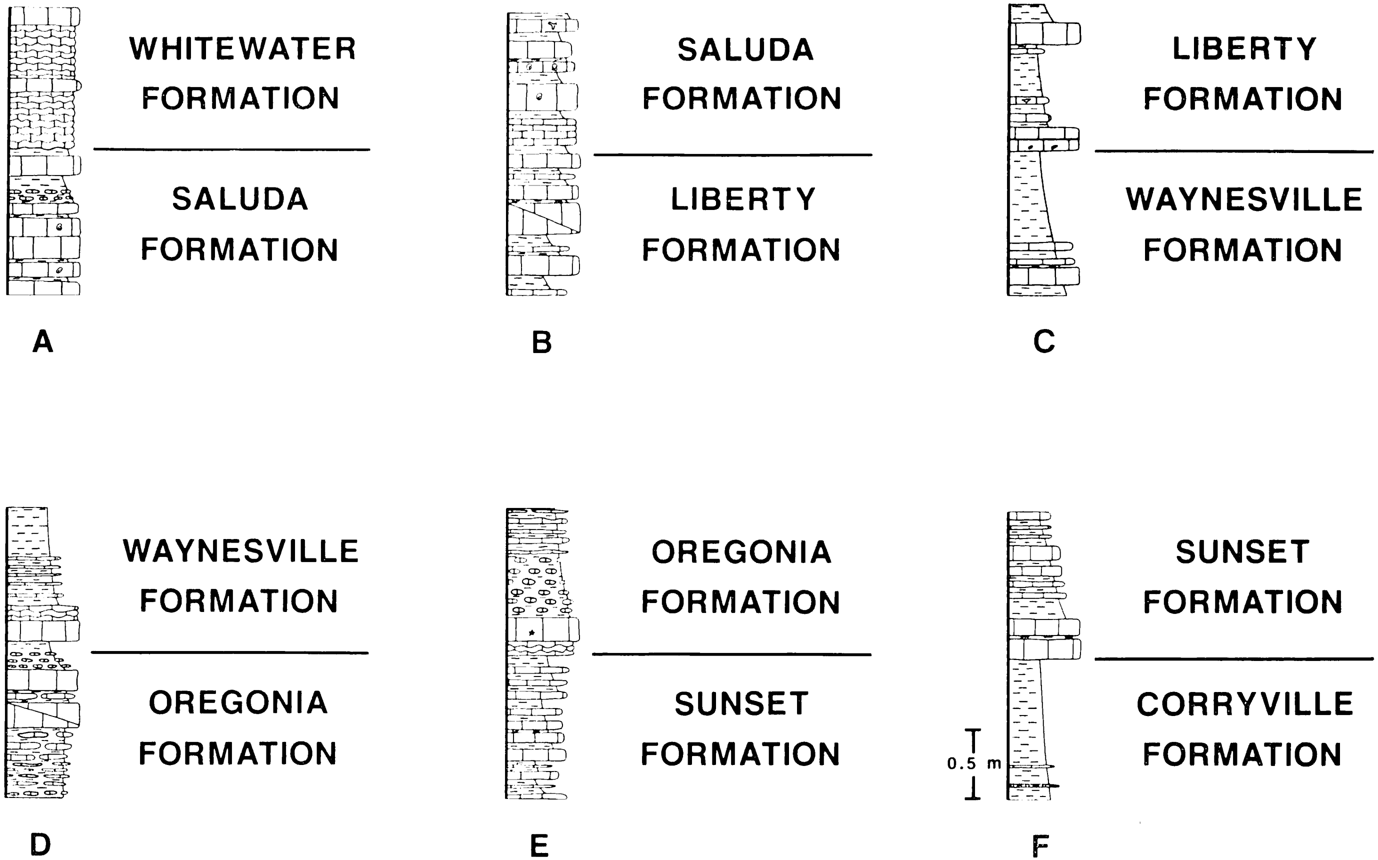


Fig. 9. Detailed description of formational contacts at the Brookville, Indiana outcrops. Stratigraphic positions of columns A through F are indicated on figure 8.

contact between the Corryville Formation and the overlying Sunset Formation is well exposed at the Brookville Dam locality (fig. 9F).

Mt. Auburn Formation.—The "Mt. Auburn or *Platystrophia lynx* Beds" were first described by Nickles (1902, p. 85-86) as follows: "Their thickness is about 20 feet. The lower five to twelve feet contain an abundance of the large Orthid, *Platystrophia lynx*, known in common parlance as double-headed Dutchman; . . . The beds are mainly blue shale, though sometimes yellowish in exposure, with some rather irregularly bedded limestone." This description is adequate for distinguishing the Mt. Auburn facies from the overlying Sunset Formation and from the underlying Corryville Formation. The description includes total thickness, faunal content, shale content, and bedding style. Bassler (1906) later ranked the "Mt. Auburn beds" as a member of the "McMillan Formation." As previously discussed, the term "McMillan Formation" is abandoned, and the "Mt. Auburn Member" is herein elevated to formational status.

Nickles' description of the "Mt. Auburn Beds" was based on exposures in the Mt. Auburn neighborhood of Cincinnati, which included the Price Hill and Clifton Heights localities. However, a specific type section was not designated. Three complete exposures of the Mt. Auburn Formation occur at the Rumpke Landfill, Middletown, and Blue Rock Road localities (fig. 1). All three localities comprise a composite reference section (app. 2). The thickness of the Mt. Auburn Formation ranges from 4.6 m to 5.1 m.

The Mt. Auburn Formation is persistent throughout the field area, occurring at least 30 km east, northeast, and north of Cincinnati. Although Nickles (1905) observed the unit along the eastern and western flanks of the Cincinnati Arch in Kentucky, it is presently considered to be an informal zone roughly correlatable with the upper part of the Grant Lake Limestone (fig. 2). Similarly, Fox (1962) described outcrops of the Mt. Auburn Formation in Clark and Jefferson Counties in Indiana. However, Brown and Lineback (1966) considered it to be an informal biostratigraphic zone in the middle of the Dillsboro Formation. In this study the Mt. Auburn Formation was observed to pinch out in a northwesterly direction between the Cincinnati area and Brookville, Ind. (fig. 4).

The Mt. Auburn Formation is composed of very thin (2 cm), fissile shales (37 percent) and abundant, thin-bedded (4 cm) limestone (63 percent). Three types of bedding are present: nodular bedding, wavy bedding, and planar bedding. Seventy-three percent of the limestone beds in the Mt. Auburn Formation are nodular. At the Middletown locality, planar bedding occurs in a thin zone, 0.7 m thick, in the middle of the formation (fig. 6). This zone is lithologically similar to the overlying Sunset Formation and may be a lateral extension (tongue) of that unit. Overall, bedding is laterally discontinuous. Two limestone varieties are present: fine-grained argillaceous packstones and wackestones (66 percent) and grainstones (34 percent). Most limestone beds are phosphatic. The majority of the shale beds are silt-poor dolomitic claystones. Although fossils are abundant and varied, the thick-shelled brachiopod, *Platystrophia pon-*

derosa auburnensis is characteristic of the formation. Other typical body fossils include bryozoans, trilobites, crinoids, gastropods, pelecypods, ostracods, and conodonts. Trace fossils include *Chondrites, Trichophycus, Paleophycus, Bergaueria,* and unnamed vertical tubes. Sedimentary structures are limited to planar and cross lamination, current-oriented fossils, and load structures.

The characteristic thin, nodular bedding of the Mt. Auburn Formation can be easily distinguished from the thick, planar bedding of the underlying Corryville Formation and the overlying Sunset Formation. The lower contact is redefined as the top of the highest planar limestone bed that underlies the lowest nodular or wavy-bedded interval. The upper contact with the Sunset Formation is redefined as the base of the lowest planar limestone bed that overlies the highest nodular or wavy-bedded interval. Both contacts are well exposed at the Blue Rock Road, Rumpke Landfill, and Middletown localities (figs. 1, 6, and 7).

Sunset Formation.—The term "Sunset Division," named after an exposure near Sunset, Ky., was first used by Foerste (1910) to describe the planar-bedded facies that occurs at the base of the "Arnheim bed." This facies was described earlier but not named by Nickles (1902) from exposures of the "Warren or *Homotrypa bassleri* Beds" in Warren County, Ohio, and by Foerste (1905) from an exposure of the "Arnheim Bed" near the town of Arnheim, in Brown County, Ohio. Nickles' original description is quoted and discussed earlier in this report and is not repeated here. Foerste (1912) later ranked the "Arnheim Bed" as a formation, and subsequent workers considered the Sunset to be a member of the "Arnheim Formation." However, the "Arnheim Formation" contains within its boundaries two very different rock facies and therefore does not possess the necessary degree of lithologic homogeneity for it to be considered a formation (1983 Stratigraphic Code, art. 24b). Accordingly, the "Arnheim Formation" is herein abandoned, and the "Sunset Member" is elevated to formational status.

The Sunset Formation is not exposed in its entirety in Ohio. The most complete outcrop occurs at the Aiken High School locality in Cincinnati, where the uppermost 6.0 m are exposed (app. 2 and figs. 1 and 6). This outcrop is designated as the principal reference section. The only complete exposure of the Sunset Formation is at the Brookville Dam locality, where it is 13.5 m thick (fig. 8). Although the term Sunset Formation is used informally in Indiana, the Brookville Dam section is well exposed and provides an excellent supplementary reference section. The Sunset Formation crops out as far north as Middletown, Ohio, as far west as Brookville, Ind., and as far east as Cincinnati. The Sunset Formation is laterally equivalent to the middle of the Dillsboro Formation of Indiana and to the lowermost Bull Fork Formation of Kentucky (fig. 2).

The Sunset Formation contains nearly equal amounts of interbedded limestone (48 percent) and shale (52 percent). Shale beds are planar, thick (8 cm), and composed of mudstone. Limestones occur as medium-thick (6 cm), closely spaced, planar beds. Overall, bedding is laterally continuous, planar, and medium thick (7 cm). Sixty-five percent of the limestones are mud-rich, skeletal packstones and wackestones. Grainstones (27 percent), siltstones (8 percent), and mudstones (trace) are also present. Body fossils include brachiopods, bryozoans, trilobites, crinoids, gastropods, pelecypods, ostracods, conodonts, and graptolites. Trace fossils include *Rhizocorallium, Diplocraterion, Trichophycus, Chondrites,* gastropod trails, and unnamed vertical tubes. Sedimentary structures include symmetric and asymmetric ripples, planar and cross lamination, flute marks, and imbricated brachiopod shells.

The planar-bedded Sunset Formation is easily distinguished from the nodular-bedded facies above and below. The lower contact is redefined as the base of the lowest planar limestone bed that overlies the highest nodular or wavy-bedded interval of the Mt. Auburn Formation. This contact is well exposed at the Blue Rock Road, Rumpke Landfill, and Middletown localities (figs. 6 and 7). In the absence of the Mt. Auburn Formation in Ohio, the lower contact of the Sunset Formation with the underlying Corryville Formation is redefined as the base of a planar limestone bed that overlies the highest shale bed greater than 0.5 m in thickness. This contact is well exposed at the Brookville Dam locality. The upper contact with the overlying Oregonia Formation is redefined as the base of the lowest wavy or nodular limestone bed that overlies the highest planar-bedded interval of the Sunset Formation. This contact is well exposed at the Aiken High School locality, where a 3 cm-thick, wavy grainstone bed overlies a planar shale bed 30 cm in thickness (fig. 6).

Oregonia Formation.—The term "Oregonia Division," named after an exposure at Oregonia, Ohio, was first used by Foerste (1910) to describe the nodular-bedded facies that occurs at the top of the "Arnheim Bed." This facies was described earlier but not named by Nickles (1902) from exposures of the "Warren or *Homotrypa bassleri* Beds" in Warren County, Ohio and by Foerste (1905) from an exposure of the "Arnheim Bed" near the town of Arnheim, in Brown County, Ohio. Nickles' original description is quoted and discussed earlier in this report and is not repeated here. Foerste (1912) later ranked the "Arnheim Bed" as a formation, and subsequent workers considered the Sunset to be a member of the "Arnheim Formation." As previously discussed, the "Arnheim Formation" is abandoned in this report, and the "Oregonia member" is elevated to formational status.

The Oregonia Formation is not completely exposed at any one locality in Ohio. The upper part of the formation is exposed at the Caesar Creek Dam locality (fig. 7), and the lower part is exposed at the Aiken High School locality (fig. 6 and app. 1). These two exposures are designated as a composite reference section. The only complete exposure of the Oregonia Formation is at the Brookville Dam locality, where it is 7.3 m thick (fig. 8). Although the term Oregonia Formation is used informally in Indiana, the Brookville Dam section is well exposed and provides an excellent supplementary reference section. The Oregonia Formation crops out as far west as Brookville, Ind. and as far east as the

Caesar Creek Dam locality in Ohio (fig. 4A). In addition, Felton (1982, personal commun.) reports an exposure of the Oregonia Formation 8 km southwest of Caesar Creek Dam, just west of the intersection of the Miami River and Interstate Highway 71. Because of a lack of outcrops, its lateral persistence to the north is unknown. The Oregonia Formation is laterally correlatable with the middle of the Dillsboro Formation of Indiana and with the lower part of the Bull Fork Formation of Kentucky (fig. 2).

The Oregonia Formation is composed of thin (4 cm), discontinuous, fissile shales (44 percent) interbedded with thin (4 cm), light gray, argillaceous limestone nodules and some wavy-to-planar limestone beds (56 percent). Fifty-two percent of the limestones in the Oregonia Formation are skeletal grainstones. Other limestone types include packstones (36 percent), wackestones (9 percent), siltstones (2 percent), and mudstones (1 percent). Shales are composed of fossiliferous mudstone. Body fossils include brachiopods, trilobites, gastropods, pelecypods, bryozoans, crinoids, ostracods, and conodonts. Trace fossils include *Diplocraterion, Chondrites, Paleophycus, Trichophycus,* and unnamed vertical tubes. Sedimentary structures are limited to planar and cross lamination, ripples, and gutter casts.

As in the Mt. Auburn Formation, the characteristic thin, nodular, and wavy bedding of the Oregonia Formation is quite distinctive from the planar-bedded units above and below. The lower contact is redefined as the base of the lowest wavy or nodular limestone bed that overlies the highest planar-bedded interval of the underlying Sunset Formation. This contact is well exposed at the Aiken High School locality (figs. 1 and 6). The upper contact is redefined as the top of the highest nodular or wavy limestone bed that underlies the lowest planar-bedded interval of the overlying Waynesville Formation. This contact is well exposed at the Caesar Creek Dam and Brookville Dam localities, where the Oregonia Formation is directly overlain by a continuous, planar shale bed (figs. 7, 8, and 9D).

Waynesville Formation.—The "Waynesville or *Bythopora meeki* Beds," named after Waynesville, Ohio, were first described by Nickles (1903, p. 205-206) as follows: "They contain some good limestone layers, two to five inches thick, suitable for ordinary building purposes, and a large amount of clay and clay shale. . . . The thickness of this division is about fifty feet. The clay is often of an intense blue, or greenish blue color. The limestones are rather of a dove color than blue, though there is considerable variation in the matter of color." This description includes total thickness, shale content, color, and limestone bedding type and thickness and is adequate for distinguishing the shale-rich, planar-bedded Waynesville facies above from the nodular-bedded Oregonia Formation below. Foerste (1906) referred to the Waynesville as a "member" of the Richmond Formation. Bassler (1906) subsequently ranked the Waynesville as a formation. Most stratigraphers have since considered the Waynesville to be a formation in the "Richmond Group." Accordingly, the Waynesville Formation is recognized in this report as a valid lithostratigraphic unit having formational status.

Nickles (1903) did not define a specific type section for the "Waynesville Beds." However, Waynesville, Ohio was referred to as a representative area and may be considered as a type area. The Waynesville Formation is not exposed in its entirety in Ohio. The most complete outcrop occurs at the Caesar Creek Dam locality, where the lowermost 14.5 m are exposed (figs. 1 and 7). This outcrop is designated as the principal reference section. The only complete exposure occurs at the Brookville Dam locality, where the Waynesville Formation (informal usage) is 37.3 m thick (fig. 8). This outcrop provides an excellent supplementary reference section. The Waynesville Formation crops out as far west as Brookville, Ind., and as far east as Caesar Creek Dam. The Waynesville Formation is laterally equivalent to the upper part of the Tanners Creek Formation of Indiana, to the middle part of the Dillsboro Formation of Indiana, and to the middle of the Bull Fork Formation of Kentucky (fig. 2). The Waynesville Formation is a shale-rich facies (67 percent) composed of medium (5 cm), widely spaced, planar-bedded limestones and very thick (11 cm), flaggy shale interbeds. Overall, bedding is laterally continuous, planar, and thick (9 cm). Seventy-nine percent of the limestones are mud-rich, skeletal packstones and wackestones. Grainstones (14 percent), siltstones (6 percent), and mudstones (1 percent) are also present. Most of the shale beds are composed of dolomitic mudstone. Body fossils include brachiopods, bryozoans, trilobites, crinoids, gastropods, pelecypods, ostracods, conodonts, and scolecodonts. Trace fossils include *Chondrites, Trichophycus, Paleophycus, Rusophycus,* and unnamed vertical tubes. Sedimentary structures are abundant and well preserved, including symmetric and asymmetric ripples, planar lamination, cross lamination, tool marks, flute marks, gutter casts, shale clasts, and imbricate brachiopod valves.

The planar-bedded Waynesville Formation is easily distinguished from the nodular-bedded Oregonia Formation below. The lower contact is redefined as the top of the highest nodular or wavy limestone bed that underlies the lowest planar-bedded interval of limestone and shale. This contact is well exposed at the Caesar Creek Dam and Brookville Dam localities, where nodular-bedded limestone of the Oregonia Formation is directly overlain by a thick, planar shale bed (figs. 7, 8, and 9D).

The Waynesville Formation is distinguished from the overlying Liberty Formation on the basis of shale content, bedding thickness, and limestone rock types. The Waynesville Formation contains more shale, is thicker bedded, and contains a higher percentage of packstones than the Liberty Formation (fig. 3). The contact between the two formations is most easily defined on the basis of shale bedding thickness. Accordingly, the top of the Waynesville Formation is redefined as the base of a planar limestone bed that overlies the highest shale bed greater than 0.5 m in thickness. This contact is well exposed at the Brookville Dam locality, where a grainstone bed directly overlies a shale bed 0.64 m thick (figs. 8 and 9C).

Liberty Formation.—The "Liberty or *Strophomena planumbona* Beds," named after Liberty, Ind., were first described by Nickles (1903, p. 207) as follows: "The strata of this subdivision consist of even-bedded limestones averaging three inches in thickness, prevailingly blue in color, with clayey and shaley layers intervening, which are also usually blue in color. . . . The thickness of this subdivision is about thirty-five feet." This description includes thickness, color, bedding type, and limestone bed thickness and is adequate for distinguishing the planar-bedded Liberty Formation from the overlying wavy-bedded Whitewater Formation. The "Liberty Beds" can be distinguished from the underlying "Waynesville beds" on the basis of shale content. The Waynesville Beds were described by Nickles (1903, p. 205) as having ". . . a large amount of clay and clay shale.", unlike the Liberty Beds. Foerste (1906) referred to the Liberty as a "member" of the Richmond Formation. Bassler (1906) subsequently ranked the Liberty as a formation. Most stratigraphers have since considered the Liberty to be a formation in the "Richmond Group." Accordingly, the Liberty Formation is recognized in this report as a valid lithostratigraphic unit having formational status.

Nickles (1903) did not define a specific type section for the "Liberty Beds." However, the following exposures were referred to as representative sections: Silver Creek in Liberty, Ind., the Whitewater River south of Richmond, Ind., the Dayton, Ohio area, and Cowan's Creek in Clinton County, Ohio. The Liberty Formation is not exposed in its entirety in Ohio. The most complete outcrop occurs at the Caesar Creek Dam locality, where the uppermost 7.0 m are exposed (fig. 7). This outcrop is designated as the principal reference section. Two additional outcrops, the Brookville Dam and Brookville North localities, provide excellent supplementary reference sections. The Liberty Formation is laterally equivalent to the upper part of the Dillsboro Formation of Indiana and to the upper part of the Bull Fork Formation of Kentucky (fig. 2). The Liberty Formation is composed of closely spaced, planar-bedded limestones (55 percent) and shales (45 percent). Limestone beds are thicker than those in Waynesville Formation (8 cm) and shales are thinner (8 cm). Overall, bedding is laterally continuous, planar, and thick (8 cm). The most abundant limestone types are packstones (44 percent) and grainstones (43 percent). Siltstones (8 percent), wackestones (3 percent), and mudstones (2 percent) are also present. Most of the shale beds are composed of dolomitic mudstone. Body fossils include brachiopods, bryozoans, trilobites, crinoids, corals, gastropods, pelecypods, cephalopods, conodonts, and ostracods. Trace fossils include *Chondrites*, *Trichophycus*, and unnamed vertical tubes. Sedimentary structures are abundant and well preserved, including symmetric and asymmetric ripples, planar lamination, cross lamination, tool marks, gutter casts, and shale clasts.

The Liberty Formation is most easily distinguished from the underlying Waynesville Formation on the basis of shale content and shale bedding thickness. The Liberty Formation contains less shale and is thinner bedded than the Waynesville Formation. The lower contact of the Liberty Formation is redefined as the base of a planar limestone bed that overlies the highest shale bed greater than 0.5 m in thickness. This contact is well exposed at the Brookville Dam locality, where a grainstone bed directly overlies a shale bed that is 0.64 m thick (figs. 8 and 9C). The upper contact with the Whitewater Formation is redefined as the base of the lowest thin, wavy limestone bed that overlies the highest planar limestone or shale bed. This contact is well exposed at the Caesar Creek Dam locality, where a thin, wavy limestone bed overlies a planar shale bed (fig. 7).

Whitewater Formation.—The "Whitewater or *Homotrypa wortheni* Beds" were first described from exposures along the banks of the Whitewater River in Richmond, Ind., by Nickles (1903, p. 208) as follows: "In this division the strata usually present a roughish, concretionary, nodular appearance, both the limestone and the shale. The color is usually brownish or yellowish, though at some localities bluish. The limestone layers, often more or less impure, are seldom over two inches thick and generally less. The thickness of this division is from forty-five to fifty feet." Nickles has adequately described a 50-foot-thick sequence of thin (<5 cm), irregularly bedded (nodular to wavy), argillaceous limestones and shales. The "Whitewater beds" are easily distinguished from the underlying planar-bedded Liberty Formation and from the overlying dolomitic strata of the Saluda Formation. Accordingly, the Whitewater Formation was subsequently recognized as a valid rock-stratigraphic unit in Indiana by Brown and Lineback (1966) and by Hatfield (1968). Fenneman (1916), Wolford (1930), Caster, Dalvé, and Pope (1955), and others have recognized the Whitewater Formation in the state of Ohio as well. However, there appears to be little agreement about its exact stratigraphic position. The Whitewater Formation directly overlies rocks of the Liberty Formation at the Madison, Ind., and Caesar Creek localities as well as rocks of *part* of the Saluda Formation at the Brookville North locality (fig. 4). This intertonguing relationship has been previously described by Caster, Dalvé, and Pope (1955) and Fox (1962). The Whitewater Formation is not exposed in its entirety in Ohio. The most complete outcrop occurs at the Caesar Creek Dam locality, where the lowermost 9.2 m are exposed (figs. 1 and 7). The formation is also well exposed at the Madison and Richmond localities in Indiana (fig. 1 and app. 1). All three localities are designated as reference sections. The Whitewater Formation is not recognized in Kentucky but is laterally equivalent to the uppermost Bull Fork and Drakes Formations (fig. 2).

The Whitewater Formation is composed of thin (4 cm), discontinuous, wavy-bedded limestones (86 percent) and very thin (2 cm) fissile shales (14 percent). Two limestone types are present; coarse-grained, skeletal grainstones (83 percent) and skeletal packstones (17 percent). Shales are composed of fossiliferous claystone. Body fossils include brachiopods, bryozoans, crinoids, trilobites, gastropods, pelecypods, and encrusting red algae and blue-green algae. Trace fossils are rare and limited to unnamed vertical tubes. Sedimentary structures are limited to ripples, imbricate brachiopod valves, and planar and cross lamination.

The upper and lower boundaries of the Whitewater Formation have never been described adequately. In this study, the lower contact of the Whitewater Formation is herein defined as the base of the lowest thin, wavy limestone bed that overlies the highest planar limestone or shale bed of the Liberty Formation. This contact is well exposed at the Caesar Creek Dam locality where a thin, wavy limestone bed overlies a planar shale bed (fig. 7). This contact is also exposed at the Madison, Ind. locality (fig. 8). However, at the Brookville North locality the Whitewater Formation occurs above rocks of part of the Saluda Formation (fig. 8). In this area, the base of the Whitewater Formation is defined as the base of the lowest thin, wavy limestone bed that overlies planar-bedded dolomitic limestone of the Saluda Formation. The upper contact of the Whitewater Formation was not observed in Ohio. Therefore, this contact cannot be defined properly at the present time. It is recommended that the top of the unit be tentatively defined as the top of the uppermost thin, wavy limestone bed regardless of the overlying lithology. In Indiana, the upper contact is well exposed at the Madison locality, where thin, wavy-bedded limestone is overlain by planar-bedded dolomitic limestones and shales of the lower part of the Saluda Formation. However, the Whitewater Formation also overlies the same lower part of the Saluda Formation at the Brookville North locality (figs. 4 and 8). Therefore, because of the intertonguing of both formations, it is again recommended that the upper contact be defined as the top of the uppermost thin, wavy limestone bed regardless of the overlying lithology.

Saluda, Elkhorn, and Drakes Formations.—The uppermost stratigraphic unit in the Cincinnatian Series is represented by three different lithofacies: the Saluda Formation, the Elkhorn Formation, and the Preachersville Member of the Drakes Formation. The Saluda Formation or "Upper Richmond Bed" was named after Saluda Creek, Jefferson County, Ind. by Foerste (1902, p. 369). Foerste (1903, p. 343-347) later described 3 lithologic divisions of the Saluda Formation within its type area: (1) a lower division consisting of soft, clayey, and shaley rocks containing 2 conspicuous coral layers (*Favistella stellata* and *Tetradium minus*); (2) a middle division consisting of massive, unfossiliferous, "banded" limestone which contains ripple marks and "suncracks"; (3) an upper division consisting of "rubbly," mottled, fine-grained limestone and fossiliferous clay. Rocks in this division contain the characteristic fossils *Lophospira hammelli* and *Cyrtocerina madisonensis*. This upper division was referred to as the "Hitz Bed," after Hitz hill in West Madison, Ind. In the decades that followed, Foerste's "Saluda Formation" became widely accepted as a valid stratigraphic unit by numerous authors, although only Cumings (1922) recognized Foerste's 3 subdivisions. The most recently published stratigraphic analyses of the Saluda Formation include those of Fox (1962), Brown and Lineback (1966), Hatfield (1968), and Gray (1972).

The Saluda Formation is currently recognized in outcrop across much of southeastern Indiana. Gray (1972, p. 19) could not recognize the unit on subsurface geophysical logs and therefore considered it to be a "member" of the Whitewater Formation. However, the apparent absence of the Saluda Formation in the subsurface does not necessitate its reduction in rank at the surface (1983 Stratigraphic Code, art. 19C and 24C). Therefore, the term "Saluda Formation" is considered in this report to be appropriate for use in Indiana. The Saluda lithofacies is also recognized throughout northwestern Kentucky, where it is considered to be a member of the Drakes Formation (Weir, Peterson, and Swadley, 1984, p. 61-63). In addition, the "Hitz Bed" has been identified and mapped in Kentucky by Kepferle (1976) and Weir, Peterson, and Swadley (1984). Hatfield (1968) also identified the Saluda Formation in northwestern Butler County, Ohio.

Although the Saluda Formation has been widely recognized and accepted as a useful lithostratigraphic unit, the literature abounds with confusing and often conflicting ideas about its stratigraphic position, rank, internal subdivisions, and boundaries. Therefore, it is highly recommended that the Saluda Formation be studied in more detail in the future to determine its stratigraphic relationships, areal extent, and lithologic characteristics on a more regional scale. To aid in this future study, an updated description of the Saluda Formation in its type area is included in this report. The Saluda Creek type section of Foerste (1902) was not described in this study. However, the nearby Madison locality (figs. 1 and 8) is well exposed and easily accessible and is herein designated as a reference section. Future workers should designate additional supplementary reference sections to help illustrate the stratigraphic relationships and lateral heterogeneity of the unit away from its type area.

The Saluda Formation is herein redefined as a formation containing primarily dolomites, dolomitic limestones, and dolomitic shales. At the Madison locality the Saluda Formation is 26.4 m thick and consists of 3 members roughly equivalent to the 3 subdivisions described by Foerste (1903). It is recognized that these 3 members may have only local significance and should be studied on a more regional scale in the future. The Lower Saluda Member is a very thick-bedded, shale-bearing facies composed of very thick (20 cm), planar-bedded limestones (43 percent), and very thick (19 cm) shale interbeds (57 percent). Limestones are primarily dolomitic wackestones and mudstones (83 percent) containing a restricted-marine fossil assemblage dominated by gastropods and ostracods. Skeletal packstones (14 percent) and grainstones (3 percent) are also present. Shale beds are slabby, silt-poor, dolomitic, and heavily bioturbated. Sedimentary structures are sparse and are limited to planar lamination, imbricate brachiopod shells, and symmetric ripples. At the Madison locality this facies contains 2 horizons of massive corals (*Tetradium* and *Favistella*). At the Brookville North locality only one coral horizon is present. The Lower Saluda Member is thickest at the Madison locality (10.1 m) and thins to 4.3 m at the Brookville North locality. The boundaries of this member are defined as the uppermost and lowermost vertical extent of the interbedded dolomitic shales and dolomitic wackestones or mudstones characteristic of this unit. At the Madison locality, the lower contact is defined as the top of the uppermost thin, wavy limestone bed of the underlying Whitewater Formation (fig. 8). This bed is directly overlain by a thick, massive, dolomitic shale bed of the Saluda Formation. At the Brookville North locality (fig. 8), the Lower Saluda Member directly overlies interbedded limestones and shales of the Liberty Formation (informal usage, see fig. 4). Here, the contact is represented by a vertical change from very fossiliferous lime grainstones and packstones to poorly fossiliferous, silty, dolomitic wackestones and mudstones. At this locality, the contact is defined as the top of the uppermost planar-bedded skeletal limestone of the Liberty Formation. This bed is directly overlain by the lowermost silty, dolomitic wackestone bed of the Saluda Formation. The upper contact of the Lower Saluda Member is also variable. At the Madison locality Lower Saluda dolomitic shale is directly overlain by the lowermost massive dolomite bed of the Middle Saluda Member. However, at the Brookville North locality the Lower Saluda Member is overlain by the Whitewater Formation. Here, the upper contact is defined as the base of the lowermost thin, wavy limestone bed that overlies the uppermost planar-bedded dolomitic wackestone bed.

The Middle Saluda Member is a massively bedded facies containing unfossiliferous, silty-to-sandy, sucrosic dolomite (69 percent) and dolomitic limestone (31 percent) in poorly defined beds. The dolomitic limestone may be texturally classified as skeletal grainstone and mudstone. Planar lamination and cross lamination are abundant, giving the unit a characteristic "banded" appearance. Other characteristic features include ripples, mudcracks, rip-up clasts, birdseye structures, omission surfaces, and occasional layers of pelletal glauconite and calcite spar-filled vugs. This member is highly resistant to erosion and stands out in relief at the Madison outcrop, where it measures 13.0 m in thickness. The base of the Middle Saluda Member is defined as the lowermost extent of the massively bedded dolomite lithology. The top of the Middle Saluda Member is defined as the uppermost extent of the massively bedded lithology, which is directly overlain by argillaceous, thin-bedded dolomudstone of the Upper Saluda Member. The Upper Saluda Member is relatively thin (3.3 m) and is composed of very light gray, argillaceous, poorly fossiliferous, color mottled dolomudstones which occur in very thin (2 cm), irregular beds. This facies is unlaminated and contains no sedimentary structures. In addition, the dolomites are soft and non-resistant to weathering and are easily distinguished from the massively bedded Middle Saluda dolomites and the overlying massively bedded Brassfield Formation. The upper contact with the Brassfield Formation is sharp and is defined as the uppermost extent of the soft, thinly bedded argillaceous dolomudstones of the Saluda Formation which are directly overlain by massive limestone of the Brassfield Formation (fig. 8).

The uppermost strata of the Cincinnatian Series have also been assigned to the Elkhorn Formation. This formation was originally named by Cumings (1908) from outcrops along Elkhorn Creek southeast of Richmond, Ind. Cumings (1922, p. 438) later described the lithology of the formation in detail:

> . . . at the top is a bed of soft clay-shale four feet thick, underlain by six feet of hard brownish limestone layers abounding in the brachiopods *Platystrophia moritura* and *Hebertella sinuata*. Below this come twenty-five feet of blocky, arenaceous limestone, underlain in turn by fifteen feet of very soft, blue, barren shale. Beneath this occur the lumpy Whitewater limestones abounding in *Rhynchotrema dentata*.

Caster, Dalvé, and Pope (1955) have reported the Elkhorn Formation in Ohio as far east as Manchester, where the unit contains a characteristic "red facies." Unfortunately, the type section of the Elkhorn Formation (Elkhorn Creek) is mostly covered by a thick layer of soil and vegetation and, thus, is difficult to describe in its present state. Because the "Elkhorn Formation" is poorly exposed in outcrop, I recommend that its use as a rock-stratigraphic unit be delayed until further exposures are studied. Perhaps core descriptions may be used to define this facies in the future.

In contrast, the uppermost facies of the Cincinnatian Series is well exposed along the eastern edge of the outcrop belt in Adams County, Ohio. A series of outcrops along Route 41, north of West Union, expose a shale-rich interval of strata at least 10.2 m thick which directly underlie the Silurian Brassfield Formation (fig. 6). This interval has been informally assigned to the Preachersville Member of the Drakes Formation by Lee (ms). This facies is shale-rich (87 percent) and contains a few thin, widely spaced carbonate beds. These carbonates include unfossiliferous, dolomitic mudstones and some non-dolomitic limestones that contain an open-marine fossil assemblage. Furthermore, a thin layer (0.92 m thick) of dark red shales and siltstones occurs near the top of the unit.

The Preachersville Member was originally described by Weir, Greene, and Simmons (1965) for strata outcropping in south-central Kentucky (48 km south of Lexington) as follows (p. D18):

> . . . contains 10 to 20 percent argillaceous, fine-grained dolomite or dolomitic limestone in resistant beds, a few inches to a few feet thick; commonly, the thicker beds are near the base of the member.

The authors concluded that this unit was probably correlative with the Liberty and Whitewater formations undivided, although they did not trace the unit northward into Ohio. Peck (1966, p. 22) concluded that the rocks outcropping in the Maysville, Ky., area (29 km southeast of the West Union outcrops) were a "northern extension of the upper part of the Preachersville Member in the type area." Weiss and others (1972) extended this nomenclature to some poorly exposed outcrops southwest of the West Union area in part of Adams County, Ohio. However, the usage of the term "Preachersville Member" in Ohio should be re-examined because the lithologic descriptions of both stratigraphic units, although similar, are not identical. Furthermore, the shale-rich strata exposed in the West Union area may indeed prove to be equivalent to the "Elkhorn Formation." Caster, Dalvé, and Pope (1955) referred to outcrops near Manchester, Ohio (just south of the West Union area) as good exposures of the Elkhorn Formation and noted the presence of a "red facies" in this area.

RELATIONSHIP TO DEPOSITIONAL MODEL

Tobin (ms, 1982) and Tobin and Pryor (1985) recently interpreted the depositional history of the type Cincinnatian of southwestern Ohio, southeastern Indiana, and northern Kentucky. The authors concluded that the type Cincinnatian was deposited on the inner part of a gently sloping, storm-dominated carbonate ramp and that deposition occurred in subenvironments ranging from the offshore zone to the supratidal zone.

The authors also concluded that the traditional Cincinnatian formations described in this report are lithofacies deposited under different paleoenvironmental conditions and therefore are highly useful for paleoenvironmental interpretation. It is hoped that by recognizing and correlating these units on a regional scale, the lateral distribution and regional variations of individual rock facies (lithotopes) may now be determined accurately. Such information is believed to be vital to the understanding of Late Ordovician paleogeography.

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APPENDIX 1

Thickness of formations described in outcrop

Outcrop locality	Formations and thickness	Total thickness
(A) Aiken High School, Cincinnati, Ohio	Sunset (6.0 m), Oregonia (2.0 m)	8.0 m
(BK) Bald Knob Hill, Cincinnati, Ohio	Kope (6.6 m), Fairview (0.6 m described)	7.2 m
(Ba) Batavia, Ohio	Kope (16.0 m)	16.0 m
(Bl) Blue Rock Road, Cincinnati, Ohio	Corryville (1.0 m), Mt. Auburn (5.1 m), Sunset (2.5 m)	8.6 m
(BD) Brookville Dam, Brookville, Ind.	Corryville (13.8 m), Sunset (13.5 m), Oregonia (7.3 m), Waynesville (37.3 m), Liberty (14.1 m)	86.0 m
(BN) Brookville North, Brookville, Ind.	Waynesville (approx. 13.5 m), Liberty (approx. 18.3 m), Saluda (4.3 m), Whitewater (1.1 m)	37.2 m
(C) Caesar Creek Dam	Oregonia (2.7 m), Waynesville (14.5 m), Liberty (7.0 m), Whitewater (9.2 m)	33.4 m
(G) Georgetown, Ohio	Kope (8.9 m), Fairview (9.2 m), Bellevue (14.8 m), Corryville (5.0 m)	37.9 m
(I) I-275 east/Ky. Rt. 445	Kope (59.0 m)	59.0 m
(M) Middletown, Ohio	Corryville (5.0 m), Mt. Auburn (4.6 m), Sunset (2.4 m)	12.0 m
(Ma) Madison, Ind.	Whitewater (10.8 m), Saluda (26.4 m)	37.2 m
(Re) Reidlin Road, Ky.	Kope (8.5 m), Fairview (32.6 m), Bellevue (4.5 m), Miamitown (0.4 m)	46.0 m

Appendix 1 (continued)

(Ri) Rt. 27 north, Richmond, Ind.	Whitewater (7.0 m)	7.0 m
(Ru) Rumpke Landfill, Cincinnati, Ohio	Corryville (13.9 m), Mt. Auburn (4.8 m), Sunset (4.6 m)	23.3 m
(WU) Rt. 41, West Union, Ohio	Drakes (10.2 m)	10.2 m

Appendix 2

Outcrop locations in the field area

Outcrop locality	Location
(A) Aiken High School	Roadcut along driveway on the north side of the school. Access is from Belmont Avenue, College Hill. Lat 39°11′34″, long 84°33′3″, Hamilton County, Ohio.
(BK) Bald Knob Hill	Roadcut along driveway, 0.3 km west of intersection of Lehman Road and State Avenue, Cincinnati. Lat 39°7′10″, long 84°32′52″, Hamilton County, Ohio.
(Ba) Batavia, Ohio	Roadcut along exit ramp from State Route 32 east, Batavia, Ohio. Outcrop is 0.8 km east of the East Fork of the Little Miami River. Lat 39°4′45″, long 84°11′4″, Clermont County, Ohio.
(Bl) Blue Rock Road	Roadcut just past entrance ramp to Blue Rock Road, Cincinnati, Ohio. Outcrop is 0.5 km southeast of intersection of I-275 and Blue Rock Road (exit 31). Lat 39°12′31″, long 84°37′23″, Hamilton County, Ohio.
(BD) Brookville Dam	Spillway section south of Brookville Lake. Access is from Route 101 north, 2.4 km north of Brookville, Ind. Lat 39°26′52″, long 84°59′34″, Franklin County, Ind.
(BN) Brookville North	Roadcuts along both sides of Route 101, 8 km north of Brookville, Ind. Lat 39°30′9″, long 84°59′34″, Franklin County, Ind.
(C) Caesar Creek Dam	Spillway cut at the southwest end of Caesar Creek Lake. Access is from Oregonia Road. Lat 39°29′9″, long 84°3′40″, Warren County, Ohio.
(G) Georgetown, Ohio	Composite section; Kope formation outcrops along banks of White Oak Creek south of Route 125. Remainder of section is a roadcut on Route 125 1.3 km west of the Georgetown city limits. Lat 38°50′25″, long 83°54′15″, Brown County, Ohio.
(I) I-275 east/Ky. Route 445	Composite Kope section; lower Kope outcrops along roadcut at intersection of KY 445 and Route 8, Fort Thomas, Ky. Upper Kope outcrops along the north side of I-275, just west of the Ohio River. Lat 39°3′13″, long 84°26′10″, Campbell County, Ky.
(M) Middletown, Ohio	Roadcut along Ohio Route 4, just south of bridge across Dicks Creek, and 0.5 km south of Route 73. Lat 39°28′35″, long 84°24′53″, Butler County, Ohio.
(Ma) Madison, Ind.	Roadcut along the east side of Indiana Route 421, approx. 3 km north of Madison. Lat 38°48′51″, long 85°17′50″, Jefferson County, Ind.
(Re) Reidlin Road, Ky.	Outcrop along Reidlin Road, just south of Covington, Ky. Access is from Route 16, 0.8 km north of I-275 (Exit 79) and 1.0 km south of Banklick Creek. Lat 39°1′41″, long 84°30′41″, Kenton County, Ky.
(Ri) Route 27 north, Richmond, Ind.	Roadcut along west side of Route 27, 1.6 km south of Richmond, Ind. Lat 39°47′38″, long 84°53′43″, Wayne County, Ind.
(Ru) Rumpke Landfill	Streamcut and landfill exposure in field east of Route 27 north (Colerain Avenue, Cincinnati), 2.4 km north of I-275. Lat 39°15′51″, long 84°34′59″, Hamilton County, Ohio.

APPENDIX 2 (continued)

(ST) Stonelick Creek	Stream cut along bank of Stonelick Creek between Belfast-Owensville Road and Route 131, 3.2 km west of Newtonsville, Ohio. Access to base of Corryville Formation at elevation 780′, 0.2 km southeast of southern end of Manila Road (see Meyer and others, 1981, fig. 34). Lat 39°9′9″, long 84°6′30″, Clermont County, Ohio.
(WU) Rt. 41, West Union, Ohio	Composite section; roadcuts along Ohio Route 41, 1.6 km north (lat 38°46′0″, long 83°1′56″) and 3.2 km north (lat 38°46′46″, long 83°1′4″) of West Union, and 8 km south (lat 38°42′9″, long 83°37′45″) of West Union, Adams County, Ohio.

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