Lithostratigraphy of the Grant Lake Limestone and Grant Lake Formation (Upper Ordovician) in Southwestern Ohio[1]

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ABSTRACT. **The Grant Lake Limestone, including, in ascending order, the Bellevue, the Corryville, and the Straight Creek Members, and the Grant Lake Formation, including, in ascending order, the Bellevue, the Corryville, and the Mount Auburn Members, are herein defined as lithostratigraphic units in southwestern Ohio. Regional bedrock mapping, shale-percentage and geophysical logs, and mean shale percentage of lithostratigraphic units demonstrate a progressive change from a limestone-dominant stratigraphic section in the Maysville, KY, region to a shale-dominant stratigraphic section in the Cincinnati, OH, region. The Grant Lake Limestone is redefined to account for the progressive decrease in limestone content observed northwestward away from Maysville, KY. The Grant Lake Formation is introduced to describe the shale-dominant lateral equivalent of the Grant Lake Limestone in the Cincinnati, OH, region. The Bellevue Limestone, the Corryville Formation, and the Mount Auburn Formation are reduced to members because, in some cases, they are not mappable at 1:62,500 or smaller scales. The Straight Creek Member is introduced to describe the limestone-dominant lateral equivalent of the shale-dominant Mount Auburn Member.**

The limestone-dominant and shale-dominant lithologies of the Grant Lake Limestone and the Grant Lake Formation can be recognized in shale-percentage and geophysical logs. Correlation between logs led to recognition of these stratigraphic units in the subsurface of southwestern Ohio.

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INTRODUCTION

Purpose

Lateral lithologic variability and the lack of regional geologic mapping have made regional correlation of lithostratigraphic units within the Upper Ordovician Cincinnatian Series difficult. Early workers relied on the occurrence of diagnostic fossils for the correlation of a given unit throughout the tri-state region of Ohio, Kentucky, and Indiana. The use of fossils as a means to define lithostratigraphic units was discouraged by the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature 1961). This change served as the impetus for re-evaluating and redefining Upper Ordovician lithostratigraphy of the tri-state region using clastic ratios, lithofacies analysis, and/or geologic mapping to define new lithostratigraphic units or revise earlier stratigraphic units (e.g., Weiss and Sweet 1964, Peck 1966, Ford 1967, Tobin 1986).

Systematic geologic mapping at map scales of 1:62,500 or smaller and regional lithologic variability have demonstrated the need for revision of some of the formal Upper Ordovician lithostratigraphic units of southwestern Ohio. The Bellevue Limestone (Ford 1967) and the Mount Auburn Formation (Tobin 1986) are not mappable at map scales of 1:62,500 or smaller in some areas of southwestern Ohio. The Grant Lake Limestone (Peck 1966) does not address the change from a limestone-dominant section at Maysville, KY, to a shale-dominant section at Cincinnati, OH. Thus, the purpose of this paper is to: 1) revise the existing lithostratigraphic nomenclature within the Grant Lake stratigraphic interval so it is mappable at map scales of 1:62,500 or smaller; 2) address the lithologic variability present between Maysville, KY, and Cincinnati, OH, by redefining existing lithostratigraphic nomenclature or defining new lithostratigraphic nomenclature; and, 3) correlate these lithostratigraphic units into the subsurface of southwestern Ohio.

Adopted Lithostratigraphic Nomenclature

The Grant Lake Limestone and the Grant Lake Formation are adopted by the Ohio Geological Survey (OGS) as lithostratigraphic units in southwestern Ohio because they are mappable at map scales of 1:62,500 or smaller. The Grant Lake Limestone is redefined to describe the progressive increase in shale observed between Maysville, KY, and Cincinnati, OH. The Grant Lake Formation is introduced to describe the shale-dominant lateral equivalent of the Grant Lake Limestone. The Bellevue, Corryville, Mount Auburn, and Straight Creek Members are used to describe the different lithologies present within the Grant Lake Limestone and Grant Lake Formation.

Stratigraphic Position

The Grant Lake Limestone and the Grant Lake Formation overlie the Miamitown Shale or the Fairview Formation and underlie the informal Arnheim formation (Fig. 1). These units represent two of 13 formal or informal formations recognized by the Ohio Geological Survey and mapped within the informal Cincinnati group of southwestern Ohio (Fig. 1).

Historical Background

The Grant Lake Limestone, named for a small lake south of Maysville, KY, was proposed by Peck (1966) to replace the McMillan Formation of Bassler (1906). The

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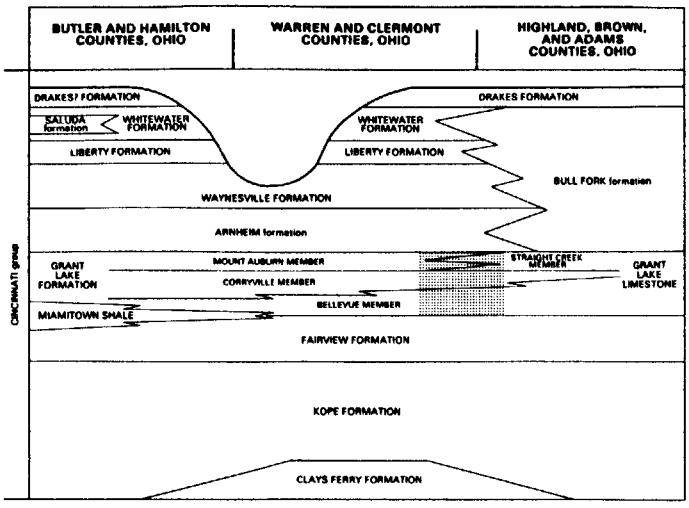


FIGURE 1. Schematic diagram illustrating Upper Ordovician lithostratigraphic nomenclature recognized by the Ohio Geological Survey in southwestern Ohio. Formal lithostratigraphic units are indicated by upper-case type. Informal lithostratigraphic units are designated by lower-case type. The area under the bold line represents the Upper Ordovician stratigraphic section exposed throughout the study area. The "valley" depicts post-Ordovician erosion of the Drakes, Whitewater, and Liberty Formations in Clermont and Hamilton counties, OH. Stippled area is the transition zone between the Grant Lake Limestone and the Grant Lake Formation.

type section was designated from a series of road cuts located along Kentucky Route 1449, about 2 km south of Maysville, KY (Peck 1966).

The Grant Lake Limestone was adopted as a formal lithostratigraphic unit by the U.S. Geological Survey (Peck 1966). The unit was subsequently mapped either as a formation, member, or tongue throughout the Upper Ordovician rocks exposed in Kentucky (Weir et al. 1984).

In Ohio, the Grant Lake Limestone was first recognized from exposures near Georgetown, OH (Peck 1966) (Fig. 2). The Grant Lake Limestone undifferentiated was mapped in a number of 7 1/2-minute quadrangles straddling the Ohio River in southern Clermont and Brown counties, OH (e.g., Gibbons and Weiss 1972, Weiss et al. 1972, Outerbridge et al. 1973, Osborne et al. 1973, Kohut et al. 1973, Luft et al. 1973, Kohut and Weiss 1981) (Fig. 2). The unit was later recognized from a limited number of exposures in central Brown and Clermont counties, OH (Lee 1974) (Fig. 2). The statewide mapping program of the Ohio Geological Survey has recognized and mapped the Grant Lake Limestone and the Grant Lake Formation over extensive areas of Brown, Butler, Clermont, Hamilton, and Warren counties, OH (Fig. 2).

The Grant Lake Formation in the Cincinnati, OH, region corresponds to: the upper portion of the Hill Quarry Beds of Orton (1873); the Bellevue, Corryville, and Mount Auburn Beds of Nickles (1902); and, the McMillan Formation with, in ascending order, the Bellevue, Corryville, and Mount Auburn Members of Bassler (1906). Nickles (1902) introduced the Bellevue, Corryville, and Mount Auburn Beds as replacements for the upper part of the Hill Quarry Beds. Reflecting the standard practices of the day, he described the lithologies associated with these beds and determined a diagnostic fossil which characterized each unit.

Bassler (1906) included the Bellevue, Corryville, and Mount Auburn Beds of Nickles (1902) as members of the newly proposed McMillan Formation. The McMillan Formation was to be introduced by Bassler and Ulrich to simplify the stratigraphy of the Cincinnati, OH, Folio of the U.S. Geological Survey. This folio was not completed, thus detailed description of the lithologies or boundaries of the McMillan Formation to replace the brief descriptions of Bassler (1906) were never published.

The McMillan Formation and associated members were adopted as formal stratigraphic units despite the fact the Cincinnati Folio was not published. Subsequent studies focused on the correlation of these units throughout the tri-state region (e.g. Nickles 1905, Cumings 1908, Foerste 1909, McEwan 1920, and Wolford 1930). These workers relied on the diagnostic fossils contained within these units because of lateral lithologic changes which occur outside the Cincinnati, OH, region.

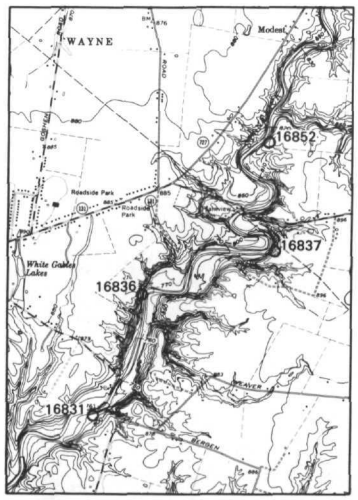
The McMillan Formation and the Bellevue, Corryville, and Mount Auburn Members were abandoned by Brown and Lineback (1966) as lithostratigraphic units in Indiana because of the emphasis placed on the faunal content by earlier stratigraphers. In Indiana, Brown and Lineback (1966) replaced these units with the Dillsboro Formation.

Geologic mapping conducted by Ford (1972, 1974) in portions of Hamilton County, OH, did not recognize the McMillan Formation, the Corryville Member, or the Mount Auburn Member because of poor and limited exposures of this interval (Fig. 2). As a result, the majority of this stratigraphic interval was mapped as undifferentiated Ordovician rocks (Ford 1972, 1974; Osborne 1970, 1974). An exception was the Bellevue Member of the McMillan Formation, which Ford (1967) elevated to the Bellevue Limestone and mapped as a formal lithostratigraphic unit in Hamilton County (Ford 1972, 1974). Ford (1967) redefined the Bellevue Member because the term had priority and was used by most geologists to describe a lithologic interval characterized by a series of thin shelly limestones as described by Nickles (1902), and not the interval characterized by the bryozoan *Monticulipora molesta*.

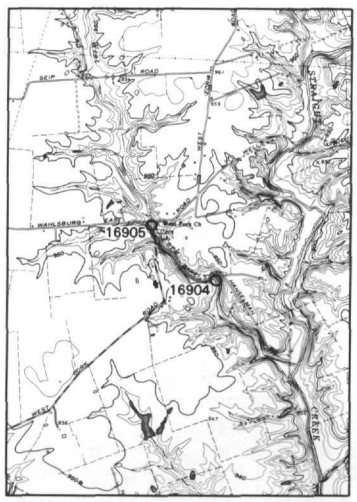
Subsequent geologic investigations focused on the unnamed or undifferentiated Ordovician strata overlying the Bellevue Limestone. Hay (1981) and Hay et al. (1981) informally introduced the Brookville formation and the Excello and Station Hollow Shale members as replacements for the McMillan Formation and associated members in southwestern Ohio and southeastern Indiana.

Tobin (1986) recognized the dual biostratigraphic and lithologic description of many of the stratigraphic units defined by Nickles. Based on a number of stratigraphic sections (Fig. 2), he proposed that these units should be used to describe the lithostratigraphy of southwestern Ohio, upon redefinition in accordance with the North American Commission on Stratigraphic Nomenclature 1983 North American Stratigraphic Code (hereafter referred to as 1983 North American Stratigraphic Code).

Tobin (1986) abandoned the McMillan Formation of Bassler (1906) throughout southwestern Ohio because; "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

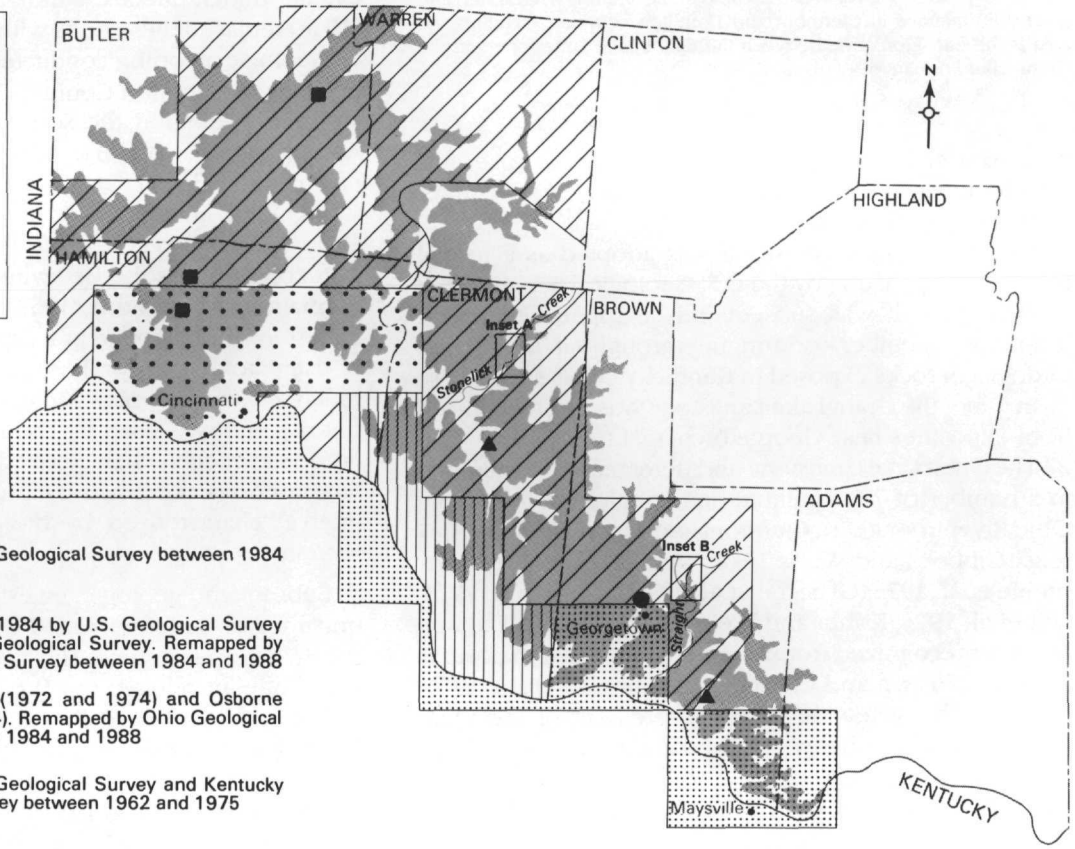


Inset A



Inset B

Location Map



Mapped by Ohio Geological Survey between 1984 and 1988

Mapped prior to 1984 by U.S. Geological Survey and Kentucky Geological Survey. Remapped by Ohio Geological Survey between 1984 and 1988

Mapped by Ford (1972 and 1974) and Osborne (1970 and 1974). Remapped by Ohio Geological Survey between 1984 and 1988

Mapped by U.S. Geological Survey and Kentucky Geological Survey between 1962 and 1975

■ Exposures studied by Tobin (1986)

▲ Exposures studied by Lee (1974)

● Exposure studied by Peck (1966), Lee (1974), and Tobin (1986)

0 10 20 miles

0 10 20 kilometers

FIGURE 2. Location of study area, status of geologic mapping in southwestern Ohio, and summary of previous studies examining the lithostratigraphy of the Grant Lake Limestone and the Grant Lake Formation stratigraphic interval. Shaded area represents the outcrop of these units. Inset A displays the location of the designated composite type section of the Grant Lake Formation. Inset B illustrates the location of the designated composite type section of the Straight Creek Member of the Grant Lake Limestone.

considered a valid formation (1983 North American Stratigraphic Code, Article 24 section b)." He replaced the McMillan Formation with the Bellevue Limestone of Ford (1967) and elevated the Corryville and Mount Auburn Beds of Nickles to formational status (Tobin 1986).

Schumacher et al. (1987a,b) and Shrake et al. (1988) informally recognized the Grant Lake Limestone as a replacement for the abandoned McMillan Formation throughout southwestern Ohio. Schumacher et al. (1987b) subdivided the Grant Lake Limestone into the Bellevue, the Corryville, and the Mount Auburn members, and informally introduced the Straight Creek member to describe the limestone-dominant lateral equivalent of the shale-dominant Mount Auburn member.

MATERIALS AND METHODS

Field geologic mapping of topographic quadrangles at the map scale of 1:24,000, measured sections, and continuous cores were used to support the lithostratigraphic revisions proposed in this paper. The contacts of the Grant Lake Limestone, Grant Lake Formation, and associated members were mapped in 42 topographic quadrangles located in southwestern Ohio. These data were transferred to map scales of 1:62,500 or smaller for future publication.

Forty-four measured sections from stream and road cut exposures and 13 continuous cores, representing a total thickness of 692 m, were measured and described, bed by bed (Appendices 1, 2). Observations included gross lithology; weathered and unweathered color of rock types; bed thickness; bedding style; bed continuity; sedimentary structures; weathering characteristics; prominent body fossils; abundance and variety of trace fossils; and, the nature of the formational and member contacts. Bed thickness was measured to the nearest 0.03 m in all cores and stratigraphic sections, except those stratigraphic sections in Clermont and Brown counties, OH, and Mason County, KY, which are rounded to the nearest 0.015 m.

Carbonate rocks were classified according to Dunham (1962). Shale rocks and shale parting characteristics were classified according to Potter et al. (1980); rock colors were determined using Goddard et al. (1951). The thicknesses of individual beds were classified according to Ingram (1954).

The authors have used shale-percentage logs, introduced by Sweet et al. (1974), for illustration of the bulk lithologic properties of the measured sections and continuous cores of this study. Shale-percentage logs are the thickness of shale, expressed as a percentage of the total thickness of limestone and shale, for each successive 0.91 m interval.

Shale-percentage logs were produced for those measured sections which contained at least 30% of the total thickness of the Bellevue and Corryville Members, or 50% of the total thickness of the Mount Auburn and Straight Creek Members (Appendices 1, 2). These percentages were chosen to maximize the use of measured stratigraphic sections, and to minimize the anomalous mean shale percentages commonly associated with short stratigraphic sections.

Mean shale percentages were calculated for the Grant Lake Limestone, the Grant Lake Formation, and the associated members (Appendices 1, 2). The mean shale percentage was obtained by summing the shale percentages for each of the 0.91 m intervals for a given unit, then dividing by the total number of 0.91 m intervals. Mean shale percentages were calculated to eliminate the considerable variation displayed between individual 0.91 m intervals. Mean shale percentage values were plotted and contour lines of equal shale percentage were drawn for the Grant Lake Limestone, the Grant Lake Formation, and their associated members (Fig. 3A,B,C,D).

Isopach maps were generated for the Grant Lake Limestone, the Grant Lake Formation, and their associated members (Fig. 4A,B,C,D). Data utilized for these maps include estimated thickness of incomplete measured sections and were based on thickness trends observed between cores and complete measured sections (Appendices 1, 2). Maximum error is 1.5 m.

RESULTS AND DISCUSSION

Justification of Adopted Lithostratigraphic Nomenclature

Two formations and four members are adopted for the stratigraphic interval between the top of the Fairview Formation or Miamitown Shale and the base of the informal Arnheim formation in the Upper Ordovician stratigraphic section of southwestern Ohio. The Grant Lake Limestone, including, in ascending order, the Bellevue, the Corryville, and the Straight Creek Members, represents the surficial and subsurface lithostratigraphy in Adams and Highland counties and portions of Brown, Clermont, and Clinton counties, OH (Figs. 1, 3). The Grant Lake Formation, including, in ascending order, the Bellevue, the Corryville, and the Mount Auburn Members, comprises the surficial and subsurface lithostratigraphy in Butler, Hamilton, and Warren counties and portions of Brown, Clermont, and Clinton counties, OH (Figs. 1, 3).

The lithostratigraphic nomenclature of this paper represents a compromise using the best qualities of the preexisting formal lithostratigraphic nomenclature given the constraints of: 1) adhering to the guidelines set forth by the 1983 North American Stratigraphic Code; 2) illustrating formal lithostratigraphic units at a map scale of 1:62,500 or smaller; 3) mapping and depicting the lithologies present within the Grant Lake Limestone and Grant Lake Formation; and, 4) mapping lithostratigraphic units which could be carried into the subsurface of southwestern Ohio.

The use of the Grant Lake Limestone adheres to Article 18, sections a and b, of the Stratigraphic Code by retaining an established stratigraphic unit, but providing a more exact lithic designation as this unit changes laterally from a limestone-dominant lithology to a shale-dominant lithology. The geographic term, Grant Lake, was retained for the shale-dominant lateral equivalent of the Grant Lake Limestone in accordance with Article 18, section b, of the Stratigraphic Code. This article states that, when the original lithic designation of a lithostratigraphic unit is inappropriate as the result of new knowledge, this should be recognized by changing the lithic designation of the unit, while retaining the original geographical term. These

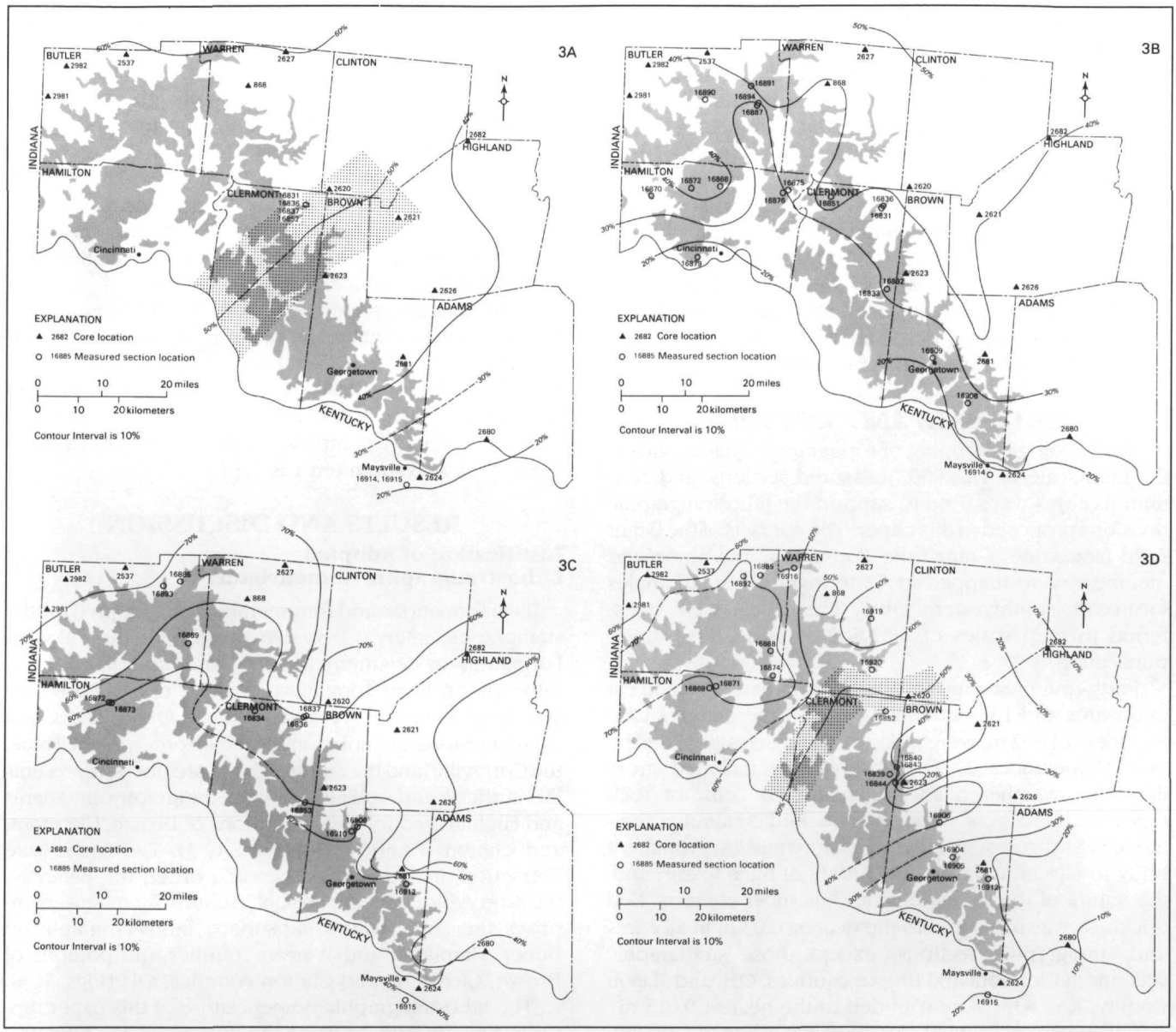


FIGURE 3. Regional variation in the mean shale percentage of the Grant Lake Limestone and the Grant Lake Formation, the Bellevue Member, the Corryville Member, the Mount Auburn Member, and the Straight Creek Member. Shaded area is the outcrop area of these units. Dashed contour lines are inferred. Figure 3A illustrates the mean shale percentage of the Grant Lake Limestone and the Grant Lake Formation. Stippled area is the transition zone between these formations. Figure 3B displays the mean shale percentage of the Bellevue Member of the Grant Lake Limestone and the Grant Lake Formation. Figure 3C shows the mean shale percentage of the Corryville Member of the Grant Lake Limestone and the Grant Lake Formation. Figure 3D illustrates the mean shale percentage of the Mount Auburn Member of the Grant Lake Formation and the Straight Creek Member of the Grant Lake Limestone. Stippled area is the transition zone between these members.

units are of sufficient thickness to map at the designated scale of 1:62,500 or smaller and have been correlated into the subsurface.

The Bellevue Limestone (Ford 1967), the Corryville Formation (Tobin 1986), and the Mount Auburn Formation (Tobin 1986) are reduced to members of the Grant Lake Limestone and/or Grant Lake Formation in accordance with Article 24, section d, of the code because, in some areas of southwestern Ohio, these units are not mappable at map scales of 1:62,500 or smaller. The thin Bellevue Limestone and Mount Auburn Formation could be mapped as a labelled line in those areas of closely-spaced topographic contours associated with steep topography, which is encouraged by Article 24, section d. However, this line would represent the contacts of the Fairview Formation and Miamitown Shale, Miamitown Shale and Bellevue Member, and Bellevue Member and Corryville Member. The representation of multiple thin lithostratigraphic units by a single labelled line would be confusing and Article 24, section d, of the Stratigraphic Code, discourages the proliferation of thin stratigraphic units.

The Bellevue Member, Corryville Member, and Mount Auburn Member are used to describe the limestone-dominant and shale-dominant lithologies within the Grant Lake stratigraphic interval. The Straight Creek Member of the Grant Lake Limestone is introduced in accordance with Article 25, section e, of the Stratigraphic Code because this unit is the limestone-dominant lateral equivalent of the shale-dominant Mount Auburn Member of the Grant Lake Limestone.

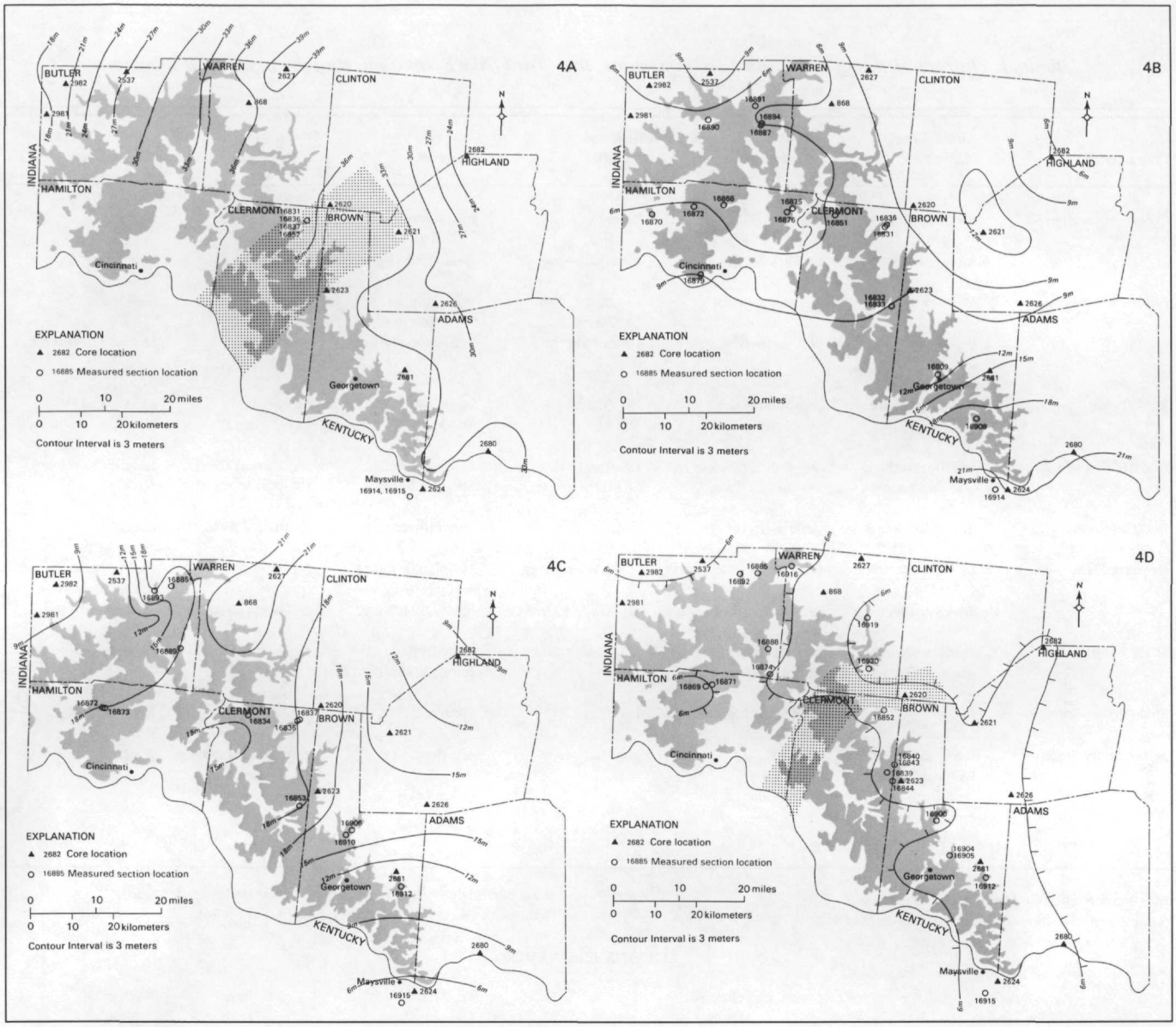


FIGURE 4. Isopach maps of the Grant Lake Limestone and Grant Lake Formation, the Bellevue Member, the Corryville Member, the Mount Auburn Member, and the Straight Creek Member. Shaded area is the outcrop area of these units. Figure 4A illustrates the thickness of the Grant Lake Limestone and the Grant Lake Formation. Stippled area is the transition zone between these formations. Figure 4B displays the thickness of the Bellevue Member of the Grant Lake Limestone and the Grant Lake Formation. Figure 4C shows the thickness of the Corryville Member of the Grant Lake Limestone and the Grant Lake Formation. Figure 4D illustrates the thickness of the Mount Auburn Member of the Grant Lake Formation, and the Straight Creek Member of the Grant Lake Limestone. Stippled area is the transition zone between these members.

Unit Descriptions

GRANT LAKE LIMESTONE. The Grant Lake Limestone as described by Peck (1966) is herein adopted with modification for southwestern Ohio. Peck (1966) defined the Grant Lake Limestone as predominantly consisting of irregular-bedded, argillaceous limestone and interbedded shale. Limestone constitutes 70-90% of the unit, and shale constitutes the remainder.

The Grant Lake Limestone as mapped in the eastern portion of southwestern Ohio is mainly irregular- to wavy-bedded, argillaceous, fossiliferous limestone and interbedded calcareous, fossiliferous shale. Subordinate amounts of planar-bedded, argillaceous, fossiliferous limestone and calcareous, sparsely fossiliferous shale increase in abundance in a northwestward direction from Maysville, KY. The mean shale percentage ranges from 21-50% (Appendices 1, 2; Fig. 3A).

The Grant Lake Limestone is herein redefined to include those stratigraphic sequences which contain less than a mean value of 50% calcareous, fossiliferous shale and predominantly irregular- to wavy-bedded, argillaceous, fossiliferous limestone. The subordinate lithologies described above are included in this redefinition of the Grant Lake Limestone (Table 1).

Peck (1966) described the lower contact of the Grant Lake Limestone as gradational. He placed the lower contact so as to separate the planar beds of alternating limestone and shale of the Fairview Formation, and the irregular to wavy beds of argillaceous limestone of the Grant Lake Limestone. Peck (1966) stated that the upper

TABLE 1

Lithologic characteristics of the Grant Lake Limestone, the Grant Lake Formation, and the associated members.

Characteristic	Grant Lake Limestone	Grant Lake Formation	Bellevue Member	Corryville Member	Mount Auburn Member	Straight Creek Member
Color[1]: unweathered	med.–lt.–gray to med.–dk.–gray	see desc. for Grant Lake Ls.	lt.–gray to med.–dk.–gray	med.–gray to med.–bluish–gray	see desc. for Grant Lake Ls.	see desc. for Grant Lake Ls.
Color[1]: weathered	Lt.–gray to yell.–gray	Lt.–gray to yell.–brown	see desc. for Grant Lake Ls.	yell.–gray to yell.–brown	lt.–olive–gray to yell.–brown	see desc. for Mount Auburn Mbr.
Rock Types	Ls.[2]–G., P., rare Sh.[3]–M.	Sh.–M. and C. Ls.–G., P., and W.	Ls.–G. and P. Sh.–M.	Ls.–P., W., and G. Sh.–M. and C.	Sh.–M. Ls.–G. and P.	Ls.–G. and P. Sh.–M.
Bed Thickness[4]	Ls.–thin to thick Sh.–thin to thick	Sh.–thin to thick Ls.–thin to thick	Ls.–thin to thick Sh.–thin	Ls.–thin to med. Sh.–thin to thick	Sh.–thin to thick Ls.–thin to med.	Ls.–thin to thick Sh.–thin
Bed Continuity	generally dcon.	generally con.	dcon.	generally con.	dcon.	dcon.
Bedding Style	Ls.–wavy to irreg. Sh.–wavy to irreg.	Sh.–planar, nod., wavy Ls.–planar, nod., wavy	Ls.–wavy to irreg. Sh.–wavy to irreg.	Ls.–planar, minor wavy or irreg. Sh.–planar, irreg.	Sh.–irreg. Ls.–nod., irreg.	Ls.–wavy, irreg., minor planar Sh.–irreg.
Shale Partings[3]	fissile with minor platy to flaggy	platy to flaggy, minor fissile	fissile with rare platy	platy to flaggy, minor fissile	fissile	fissile
Shale Fossil Content	fos.	sp. fos. to fos.	fos.	sp. fos.	fos. to sp. fos.	fos.
Sedimentary Structures	rare intraclasts, sole marks, graded bedding, cross–lamination, ripple marks	see desc. for Grant Lake Ls.	generally rare	see desc. for Grant Lake Ls.	rare graded beds, load casts	generally rare

[1]Rock colors after Goddard et al. (1951).
[2]Limestones classified according to Dunham (1962).
[3]Shale and shale parting characteristics after Potter et al. (1980).
[4]Bed thickness classified according to Ingram (1954).

LIST OF ABBREVIATIONS

med.	–	medium	yell.	–	yellowish	Sh.	–	Shale	irreg.	–	irregular
lt.	–	light	Mbr.	–	Member	M.	–	Mudshale	nod.	–	nodular
dk.	–	dark	G.	–	Grainstone	C.	–	Clayshale	fos.	–	fossiliferous
desc.	–	description	P.	–	Packstone	dcon.	–	discontinuous	sp. fos.	–	sparsely fossiliferous
Ls.	–	Limestone	W.	–	Wackestone	con.	–	continuous			

contact ranged from sharp in some places to gradational in others. He placed the upper contact so as to separate the irregular to wavy limestone beds of the Grant Lake Limestone from the alternating limestone and shale of the Bull Fork Formation. These contacts have been adopted for the Grant Lake Limestone as mapped in Ohio.

GRANT LAKE FORMATION. The Grant Lake Formation is herein introduced as a lateral equivalent of the Grant Lake Limestone. The Grant Lake Formation consists of primarily interbedded, calcareous, sparsely fossiliferous shale and planar-bedded, fossiliferous, argillaceous limestone. Subordinate amounts of nodular-, wavy-, and irregular-bedded argillaceous limestone and calcareous, fossiliferous shale occur throughout the unit. The mean shale percentage ranges from 50-60% (Appendices 1, 2; Fig. 3A; Table 1).

The lower contact of the Grant Lake Formation with the Fairview Formation and Miamitown Shale is highly variable, ranging from sharp to gradational to intertonguing. The contact, where sharp, is herein defined as the base of the lowermost wavy- to irregular-bedded limestone bed or fossiliferous, fissile-parted shale bed of the Bellevue Member of the Grant Lake Formation. The contact overlies the planar-bedded limestone and sparsely fossiliferous, platy-parted shale of the Fairview Formation or the planar- to nodular-bedded limestone and sparsely fossiliferous, platy-parted shale of the Miamitown Shale. The contact, where gradational, is herein arbitrarily placed midway within the 0.3-0.7 m transition zone separating the Fairview Formation lithology and the Bellevue Member lithology. The contact, where intertonguing, is defined at distinct levels depending on the dominance of one unit versus the other. In those cases where the Bellevue Member lithology dominates over the Fairview Formation lithology and/or Miamitown Shale lithology, the contact is placed at the base of the lowermost tongue of Bellevue Member lithology. In those cases where

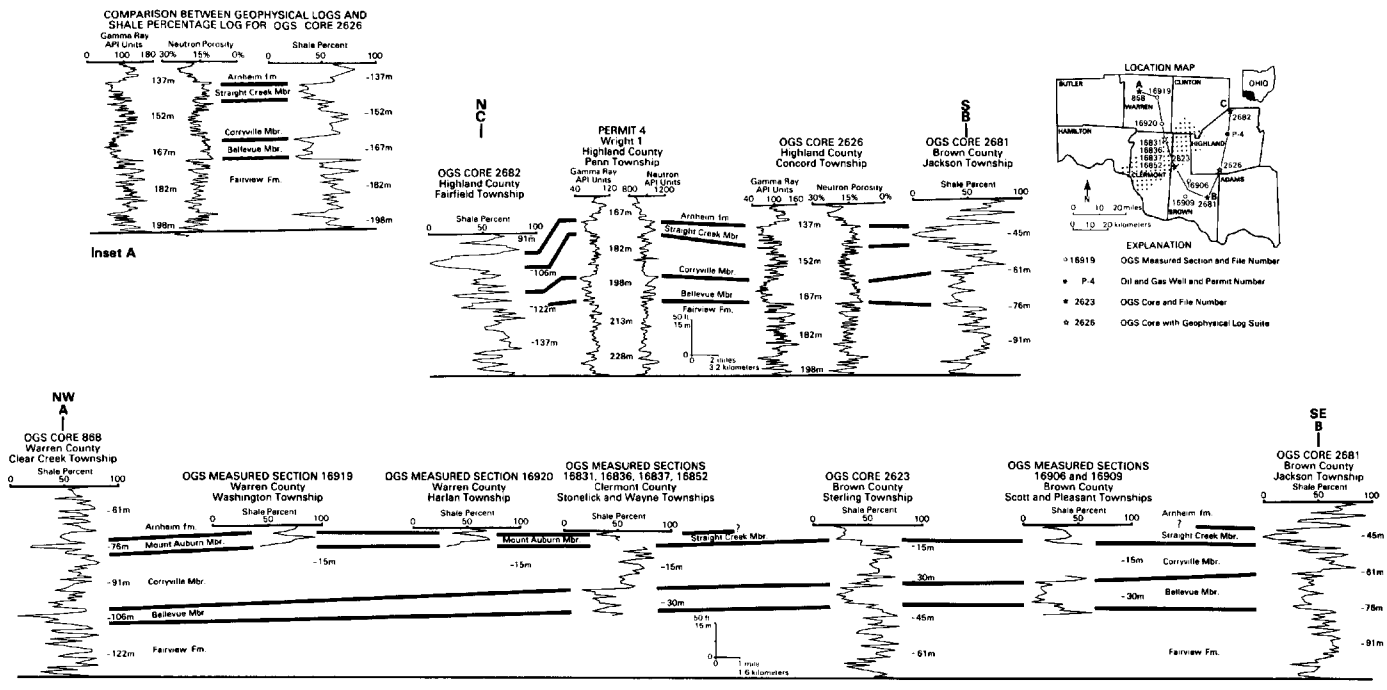


FIGURE 5. Regional correlation of the Grant Lake Limestone, the Grant Lake Formation, and associated members, using shale-percentage logs and geophysical logs. Datum is the base of the Fairview Formation. Stippled area on the location map is the transition zone between the Grant Lake Limestone and the Grant Lake Formation. Inset A is the comparison of a shale-percentage log and geophysical logs. Cross-section A-B illustrates the correlation of shale-percentage logs from surface exposures to continuous cores. Cross-section B-C displays the correlation of shale-percentage logs to geophysical logs in the subsurface of the study area.

the Fairview Formation and/or Miamitown Shale dominates over the Bellevue Member in the zone of intertonguing, the contact is placed at the base of the lowermost Bellevue Member lithology overlying the zone of intertonguing. Thinner tongues of Bellevue Member are present in the Fairview Formation and/or Miamitown Shale.

The upper contact of the Grant Lake Formation is sharp to gradational over 0.3-1.0 m. The contact, where sharp, is defined at the top of the uppermost nodular- to irregular-bedded limestone or fossiliferous, fissile-parted shale of the Mount Auburn Member of the Grant Lake Formation. This contact, where gradational, is arbitrarily placed midway within the zone of transition between the lithology of the Mount Auburn Member and the planar- to lenticular-bedded limestone and sparsely fossiliferous, platy-parted shale of the Arnheim formation. The type section of the Grant Lake Limestone has become somewhat overgrown with vegetation and is of limited value. Therefore, the authors designate the road cuts created for Kentucky Route 11, near Maysville, KY, as principal reference sections for the Grant Lake Limestone (OGS measured sections 16914, 16915, 16921). Ohio Geological Survey cores 2621, 2623, 2624, 2626, 2680, 2681, and 2682 are designated as principal reference sections in southwestern Ohio. These cores illustrate the lateral variation in mean shale percentage and subtle variations in lithology that characterize the Grant Lake Limestone in southwestern Ohio.

The type section of the proposed Grant Lake Formation is herein designated as the composite section exposed along Stonelick Creek in Clermont County, OH (Fig. 2, inset A; Appendix 3). Ohio Geological Survey cores 868, 2537, 2620, 2627, 2981, and 2982 are designated as principal reference sections.

The Grant Lake Limestone and the Grant Lake Formation display a relatively uniform thickness of 33-36 m along the outcrop belt in southwestern Ohio (Fig. 4A). The subsurface thickness of both units ranges from <18 m to >39 m. The variation in thickness is related to the thickening and thinning trends of the Bellevue and Corryville Members (Fig. 4B,C; Fig. 5).

Correlations utilizing conodont and graptolite biostratigraphy throughout Ohio, Indiana, and Kentucky have shown that the Grant Lake Limestone and Grant Lake Formation are markedly diachronous (Sweet and Bergström 1971, Sweet 1979, Bergström and Mitchell 1986). Rocks of the Grant Lake Limestone and the Grant Lake Formation correlate to the middle Maysvillian Stage of the Cincinnatian Series in southwestern Ohio (Sweet 1979). Outside of Ohio, conodont and graptolite biostratigraphy indicates these units correlate to the middle portion of the Dillsboro Formation of Indiana, and the Grant Lake Limestone and the lower and middle portions of the Ashlock Formation of Kentucky (Sweet 1979, Bergström and Mitchell 1986).

The Grant Lake Limestone and Grant Lake Formation have been correlated from surface exposures into the shallow subsurface using shale-percentage logs (Fig. 5). The progressive decrease in the amount of limestone distinguishing the Grant Lake Limestone from the Grant Lake Formation is illustrated in a cross-section extending northwestward from Brown County, OH, to Warren County, OH (Fig. 5, cross-section A-B). The limestone-dominant Bellevue and Straight Creek Members are easily distinguished from the shale-dominant Fairview Formation, Corryville Member, and informal Arnheim formation (Fig. 5, cross-section A-B). The shale-dominant Mount Auburn Member was recognized and correlated on the basis of two characteristic limy tongues

containing nodular-bedded limestone (Fig. 5, cross-section A-B). The lateral change from the limestone-dominant Straight Creek Member to the shale-dominant Mount Auburn Member is also illustrated (Fig. 5, cross-section A-B).

The Grant Lake Limestone and the Grant Lake Formation have been correlated into the subsurface by comparing the diagnostic signatures of shale-percentage logs and geophysical logs (e.g., Fig. 5, inset A). The limestone-dominant and shale-dominant members of the Grant Lake Limestone are excellent markers and are easily traced into the subsurface (Fig. 5, cross-section B-C). Additional subsurface investigations are required to determine the lateral extent of the Grant Lake Limestone and Grant Lake Formation outside of southwestern Ohio.

Bellevue Member. The lithology of the Bellevue Member of the Grant Lake Limestone and the Grant Lake Formation is primarily interbedded, wavy- to irregular-bedded limestone and irregular-bedded, fissile-parted, fossiliferous shale. Subordinate amounts of interbedded planar- to lenticular-bedded, argillaceous limestone and planar-bedded, platy- to flaggy-parted, sparsely fossiliferous shale occur throughout the member, particularly in Adams and Brown counties, OH. The mean shale percentage ranges from 17-47% (Appendices 1, 2; Fig. 3B; Table 1).

The lower contact of the Bellevue Member has been discussed in the description of the lower contact of the Grant Lake Limestone and the Grant Lake Formation, and will not be repeated here. The upper contact between the Bellevue and Corryville Members is sharp to gradational. The contact, where sharp, is placed at the top of the highest wavy- to irregular-bedded limestone or fissile-parted, fossiliferous shale of the Bellevue below the planar- or lenticular-bedded limestone and platy-parted, sparsely fossiliferous shale of the Corryville. The contact, where gradational, is arbitrarily placed midway within the 0.3-2.0 m transition zone between the typical Bellevue lithology and the Corryville lithology.

The Bellevue Member is differentiated from the overlying Corryville Member by mean shale percentage, limestone bedding style, shale partings characteristics, and shale fossil content. The range of mean shale percentages is 17-47% for the Bellevue Member versus 34-74% for the Corryville Member (Appendices 1, 2; Fig. 3B,C). Limestone beds in the Bellevue are principally wavy to irregular; limestone beds in the Corryville are generally planar to lenticular. Shale beds in the Bellevue display primarily fissile partings and are fossiliferous; shale beds in the Corryville are platy- to flaggy-parted and sparsely fossiliferous. However, intertonguing between these members is not uncommon. The intertonguing of these lithologies becomes more pronounced in Brown, Butler, and Hamilton counties, OH. In these counties, it is not uncommon to encounter 1-2 m thick intervals of Bellevue lithology within the Corryville Member.

The thickness of the Bellevue Member ranges from <6 m to >21 m (Fig. 4B). The Bellevue is relatively uniform in thickness over most of Butler, Clermont, Hamilton, and Warren counties, OH. The unit displays a minor increase in thickness in Clinton and Highland counties, OH, and a major increase in thickness in southern Brown and Adams counties, OH (Fig. 4B).

Corryville Member. The lithology of the Corryville Member of the Grant Lake Limestone and the Grant Lake Formation is primarily interbedded, planar- to lenticular-bedded limestone and planar-bedded, platy- to flaggy-parted, sparsely fossiliferous shale. Minor amounts of interbedded irregular- to wavy-bedded limestone and irregular-bedded, fissile-parted, fossiliferous shale occur as discrete zones within the Corryville Member. The mean shale percentage ranges from 34-74% (Appendices 1, 2; Fig. 3C; Table 1).

The upper contact between the Corryville and the Mount Auburn and Straight Creek Members ranges from sharp to gradational. The contact, where sharp, is placed at the top of the planar- to lenticular-bedded limestone or platy- to flaggy-parted, sparsely fossiliferous shale underlying the typical Mount Auburn lithology or Straight Creek lithology. The contact, where gradational, is placed midway in the zone of transition between the typical Corryville lithology and the typical Mount Auburn lithology or Straight Creek lithology.

The Corryville Member is differentiated from the overlying Mount Auburn and Straight Creek Members by limestone bedding style, shale parting characteristics, and shale fossil content. The planar- to lenticular-bedded limestone in the Corryville Member differs from the nodular-bedded limestone in the Mount Auburn or wavy- to irregular-bedded limestone in the Straight Creek. The platy- to flaggy-parted, sparsely fossiliferous shale in the Corryville Member differs from the fissile-parted, fossiliferous shale of the Mount Auburn and Straight Creek Members.

The thickness of the Corryville Member ranges from <6 m to >21 m (Fig. 4C). The thickness reaches a maximum of 21+ m in Warren County, OH, and gradually thins to the west, south, southeast, and east. The thinning of the unit in southern Adams and Brown counties, OH, corresponds to the thickening of the underlying Bellevue Member in this area. This thinning-thickening relationship was not observed elsewhere in southwestern Ohio.

Mount Auburn Member. The lithology of the Mount Auburn Member of the Grant Lake Formation is mainly interbedded, irregular-bedded, fissile-parted, fossiliferous shale and wavy- to nodular-bedded limestone. Subordinate amounts of interbedded planar-bedded limestone and planar-bedded, platy-parted, sparsely fossiliferous shale are present. The mean shale percentage ranges from 50-79% (Appendices 1, 2; Fig. 3D; Table 1).

The upper contact of the Mount Auburn Member has been discussed in the description of the upper contact of the Grant Lake Formation and will not be repeated here. The lateral contact with the Straight Creek Member is gradational. A 10-15 km wide transition zone meanders from southeastern Clinton County, OH, to southeastern Clermont County, OH (Fig. 3D).

The Mount Auburn Member is differentiated from the laterally equivalent Straight Creek Member by mean shale percentage and limestone bedding style. The range of mean shale percentage is 50-79% for the Mount Auburn Member versus 12-50% for the Straight Creek Member (Appendices 1, 2; Fig. 3D). Limestone bedding style differs

from predominantly nodular in the Mount Auburn to wavy to irregular in the Straight Creek.

The thickness of the Mount Auburn Member ranges from <6 m to >8 m (Appendix 2; Fig. 4D). The Mount Auburn Member attains a maximum thickness of >8 m in Warren County, OH, and thins to the west, south, and east (Fig. 4D).

In this report, the stratotypes of the Bellevue Limestone, the Corryville Formation, and the Mount Auburn Formation designated by Ford (1967) and Tobin (1986) are supplemented with a large number of reference sections to illustrate the lateral changes in mean shale percentage, thickness, and lithology (Appendices 1, 2; Fig. 3B,C,D). Core and measured-section descriptions representing these reference sections are not included here, but are on open file at the Ohio Geological Survey.

Straight Creek Member. The lithology of the Straight Creek Member of the Grant Lake Limestone is characterized by interbedded, wavy- to irregular-bedded limestone and irregular-bedded, fissile-parted, fossiliferous shale. The mean shale percentage ranges from 12-50% (Fig. 3D; Table 1).

The upper contact of the Straight Creek Member has been described in the discussion of the upper contact of the Grant Lake Limestone and will not be repeated here. The discussion of the gradational contact with the Mount Auburn Member can be found in the section describing the Mount Auburn Member.

The thickness of the Straight Creek Member ranges from <6 m to >8 m (Appendices 1, 2; Fig. 4D). The Straight Creek Member exhibits a slight thinning trend from >8 m in the vicinity of Maysville, KY, to <6 m in the vicinity of northeastern Clermont County, OH (Fig. 4D).

The composite type section of the Straight Creek Member of the Grant Lake Limestone is herein designated from two principal reference sections located along the West Fork of Straight Creek in central Brown County, OH (Appendix 3; Fig. 2, inset B). The Straight Creek Member is not to be confused with the informal Straight Creek coal bed, a name used for an extensively mined coal bed along the course of Straight Creek in Bell County, KY (Wanless 1939).

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Appendix 1

Measured section data.

OGS File Number	County	Stratigraphic Unit(s)••	Measured Thickness• (meters)	Estimated Unit Thickness (meters)	Percentage Unit Measured (approximate)	Mean Shale Percentage of Interval Measured
16831	Clermont	Bell.	6.1	7.6	75	35
16832–16833+	Clermont	Bell.	3.2	9.1	35	31
16834	Clermont	Cor.	7.7	15.8	45	58
16836	Clermont	Bell.–Cor.	2.8–8.6	8.0–18.1	35–45	31–54
16837	Clermont	Cor.	12.5	18.2	70	69
16839	Clermont	Str.	5.9	6.7	85	46
16840	Clermont	Str.	5.5	6.4	80	38
16843	Clermont	Str.	4.9	7.0	70	39
16844	Clermont	Str.	3.9	7.1	55	39
16851	Clermont	Bell.	6.8	6.8	100	45
16852	Clermont	Mt.A.	5.1	6.8	75	45
16853	Clermont	Cor.	6.4	18.2	35	50
16868	Hamilton	Bell.	4.2	5.3	80	41
16869	Hamilton	Mt.A.	6.7	6.7	100	79
16870	Hamilton	Bell.	4.8	6.4	75	34
16871	Hamilton	Mt.A.	5.2	5.2	100	61
16872	Hamilton	Bell.–Cor.	6.2–5.6	6.2–18.2	100–30	42–57
16873	Hamilton	Cor.	11.2	18.2	60	45
16874	Butler	Mt.A.	6.0	6.0	100	78
16875	Hamilton	Bell.	2.5	4.2	60	31
16876	Hamilton	Bell.	2.7	4.5	60	25
16879	Hamilton	Bell.	6.8	9.1	75	17
16885	Butler	Cor.–Mt.A.	5.0–5.2	16.7–5.2	30–100	67–68
16887	Butler	Bell.	3.7	4.6	80	26
16888	Butler	Mt.A.	4.5	4.5	100	72
16889	Butler	Cor.	7.4	18.5	40	55
16890	Butler	Bell.	4.4	4.9	90	35
16891	Butler	Bell.	3.8	4.8	80	40
16892	Butler	Mt.A.	3.6	4.8	75	76
16893	Butler	Cor.	5.5	18.3	30	69
16894	Butler	Bell.	6.5	6.5	100	39
16904–16905+	Brown	Str.	7.9	7.9	100	24
16906	Brown	Cor.–Str.	4.0–5.5	4.0–16.7	100–30	40–40
16908	Brown	Bell.	7.5	18.3	40	23
16909	Brown	Bell.	11.8	11.8	100	22
16910	Brown	Cor.	6.5	16.2	40	43
16912	Brown	Cor.–Str.	3.4–5.5	11.3–8.5	30–65	34–22
16914	Mason, KY	Bell.	21.9	23.0	95	18
16915	Mason, KY	Cor.–Str.	2.7–4.4	4.2–8.8	65–50	44–20
16916	Warren	Mt.A.	5.2	5.2	100	61
16919	Warren	Mt.A.	4.8	4.8	100	69
16920	Warren	Mt.A.	5.1	5.1	100	53

• Rounded to nearest 0.1 meter.

•• Bell.–Bellevue Member; Cor.–Corryville Member; Str.–Straight Creek Member; Mt.A.–Mount Auburn Member.

\+ Composite Measured Section.

APPENDIX 2

Continuous core data.

OGS File Number	County	Stratigraphic Units+	Measured Thickness• (meters)	Mean Shale Percentage of Interval Measured
868	Warren	GLF.	35.6	56
		Bell.	6.4	39
		Cor.	22.8	61
		Mt.A.	6.4	48
2537	Butler	GLF.	27.3	59
		Bell.	10.0	41
		Cor.	10.9	72
		Mt.A.	6.4	59
2620	Clinton	GLF.	35.8	54
		Bell.	9.3	44
		Cor.	20.0	62
		Mt.A.	6.5	50
2621	Highland	GLL.	34.4	45
		Bell.	14.6	41
		Cor.	13.7	56
		Str.	6.1	32
2623	Brown	GLL.	34.3	45
		Bell.	9.1	36
		Cor.	19.1	55
		Str.	6.1••	16•••
2624	Mason, KY	GLL.	35.0	23
		Bell.	21.3	19
		Cor.	4.9	38
		Str.	8.2	25
2626	Highland	GLL.	31.0	47
		Bell.	8.2	35
		Cor.	16.4	57
		Str.	6.4	37
2627	Warren	GLF.	40.1	60
		Bell.	10.0	47
		Cor.	21.9	68
		Mt.A.	8.2	54
2680	Adams	GLL.	35.6	25
		Bell.	21.0	23
		Cor.	8.2	39
		Str.	6.4	12
2681	Brown	GLL.	34.6	42
		Bell.	15.5	39
		Cor.	10.9	60
		Str.	8.2	21
2682	Highland	GLL.	22.8	39
		Bell.	6.4	41
		Cor.	10.0	52
		Str.	6.4	12
2981	Butler	GLF.	17.2	58
		Bell.	3.8	37
		Cor.	7.7	71
		Mt.A.	5.7	57
2982	Butler	GLF.	20.8	56
		Bell.	6.9	34
		Cor.	7.7	74
		Mt.A.	6.2	60

• Thickness is 100% of unit unless noted.
•• 90% of this unit is present in this core.
••• Core loss probably accounts for this low figure.
+ GLF.–Grant Lake Formation; GLL.–Grant Lake Limestone; Bell.–Bellevue Member; Cor.–Corryville Member; Mt.A.–Mount Auburn Member; Str.–Straight Creek Member.

APPENDIX 3

Condensed type section descriptions.

GRANT LAKE FORMATION

The composite type of the Grant Lake Formation is designated from four measured sections located along Stonelick Creek, Stonelick Township, Clermont County, OH (Goshen and Newtonsville 7.5-minute quadrangles) (Fig. 1). Ohio Geological Survey measured sections 16831, 16836, 16837, and 16852 were selected as the type section. Section 16831 is located 30 meters southwest of the Belfast-Owensville Road bridge crossing Stonelick Creek. Using the Ohio Coordinate System, the base of this section is located at coordinates 1,538,700 X, 427,400 Y, South Zone. Section 16836 is located 1,150 meters north-northeast of the Belfast-Owensville Road bridge crossing Stonelick Creek. Using the Ohio Coordinate System, the base of this section is located at coordinates 1,540,200 X, 430,900 Y, South Zone. Section 16837 is located 450 meters southeast of the Ohio Route 131 bridge crossing Stonelick Creek. Using the Ohio Coordinate System, the base of this section is located at coordinates 1,543,800 X, 432,200 Y, South Zone. Section 16852 is located 600 meters north of the Ohio Route 131 bridge crossing Stonelick Creek. Using the Ohio Coordinate System, the base of this section is located at coordinates 1,543,500 X, 435,200 Y, South Zone. (Measured by G. A. Schumacher, D. L. Shrake, K. E. Vorbau, and J. D. Vormelker.)

	Thickness (meters)
Fairview Formation (incomplete): Limestone (50%) interbedded with shale (50%). Limestone beds are medium-light-gray (N6) to medium-dark-gray (N4), weathering yellowish gray (5 Y 8/1); contain skeletal fragments, sparry cement, and argillaceous material; grainstones and packstones; thin to thick beds; continuous, planar bedding; abundant bryozoans, brachiopods, and trace fossils. Sedimentary structures include graded bedding, ripple marks, parallel and cross-lamination, and current oriented elongate fossils. Shale beds are medium-light-gray to medium-dark-gray, weathering yellowish gray, calcareous; silty; sparsely fossiliferous; mudshales to clayshales; thin to medium beds; continuous, planar bedding; platy- to flaggy-partings. Upper contact of the Fairview Formation intertongues with the Grant Lake Formation. Contact with the Grant Lake Formation is placed at the base of the lowermost tongue of the Bellevue Member of the Grant Lake Formation.	2.2
Grant Lake Formation—Bellevue Member: Limestone (65%) interbedded with shale (35%). Limestone beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; contain skeletal fragments, sparry cement, and argillaceous material; grainstones; thin to thick beds; discontinuous, wavy-bedding; abundant brachiopods and bryozoans. Shale beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; calcareous; silty; fossiliferous; mudshales to clayshales; thin to medium beds; discontinuous, wavy-bedding; fissile-partings. Contact with Corryville Member is sharp.	7.6
Grant Lake Formation—Corryville Member: Shale (63%) interbedded with limestone (37%). Shale beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; calcareous; silty; sparsely fossiliferous; mudshales to clayshales; thin to thick beds; continuous, planar- to lenticular-bedding; platy- to flaggy-partings. Limestone beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; contain skeletal fragments, sparry cement, and argillaceous material; packstones, grainstones, and wackestones; thin to medium beds; continuous, planar- to lenticular-bedding, abundant trilobites, bryozoans, brachiopods, and pelmatozoans. Sedimentary structures include graded bedding, sole marks, shale intraclasts, parallel and cross-lamination, ripple marks, and current-aligned fossils. Thin intervals of Bellevue lithology may be present. Contact with the Mount Auburn Member is gradational.	18.2

APPENDIX 3 *(continued)*

	Thickness (meters)
Grant Lake Formation—Mount Auburn Member (incomplete): Shale (~50%) interbedded with limestone (~50%). Shale beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; calcareous; silty; fossiliferous; mudshales to clayshales; thin to thick beds; continuous, irregular bedding; fissile-partings. Limestone beds are medium-light-gray to medium-dark-gray, weathering yellowish gray; contain skeletal fragments, sparry cement, and argillaceous material; grainstones to packstones; thin to medium beds; discontinuous nodular-, wavy-, or irregular-bedding; abundant brachiopods. Contact with the Arnheim formation (informal) is gradational. **Note:** The lower 2 meters of the Mount Auburn Member is covered in section 16852. Thus, percentages of shale and limestone are approximate.	6.4
Arnheim formation (informal) (incomplete): Shale interbedded with limestone. Shale beds are medium gray, weathering light gray (N7); calcareous; silty; sparsely fossiliferous; thin to medium beds with a few planar beds of argillaceous, sparsely fossiliferous, limestone. Unit poorly exposed; not measured, about 4 meters of unit present.	

GRANT LAKE LIMESTONE—STRAIGHT CREEK MEMBER

The composite type section of the Straight Creek Member of the Grant Lake Limestone is designated from two measured sections located along the West Fork of Straight Creek, Franklin Township, Brown County, OH (Ash Ridge 7.5-minute quadrangle) (Fig. 1). Ohio Geological Survey measured section 16904 is located 1,185 meters northwest of the junction of the West Fork of Straight Creek with Straight Creek. Using the Ohio Coordinate System, the base of the lower section is located at coordinates 1,615,250 X, 333,100 Y, South Zone. Ohio Geological Survey measured section 19605 is located 760 meters northwest of section 16904. Using the Ohio Coordinate System, the base of the upper section is located at coordinates 1,613,500 X, 334,600 Y, South Zone. (Measured by G. A. Schumacher.)

Grant Lake Limestone—Corryville Member (incomplete): Limestone (68%) interbedded with shale (32%). Limestone beds are medium-light-gray (N6) to medium-dark-gray (N4), weathering light gray (N7); contain skeletal fragments, sparry cements, and argillaceous material; grainstones to packstones; thin to medium beds; continuous, irregular- to planar-bedding; abundant trilobites, bryozoans, brachiopods, and trace fossils. Sedimentary structures include graded bedding, parallel lamination, ripple and cross-lamination, and aligned conical cephalopods. Shale beds are medium-light-gray to medium-dark-gray, weathering light gray; calcareous, silty, and sparsely fossiliferous; mudshales to claystones; thin beds; continuous, irregular- to planar-bedding; and platy- to flaggy-partings. Contact with Straight Creek Member is sharp.	0.9
Grant Lake Limestone—Straight Creek Member: Limestone (76%) interbedded with shale (24%). Limestone beds are of two types. Dominant type is medium-light-gray to medium-dark-gray, weathering moderate-yellowish-brown (5Y 8/1); contain skeletal fragments, sparry cements, and argillaceous material; grainstones; thin to thick beds; discontinuous, wavy- to irregular-bedding; abundant brachiopods and bryozoans. Minor type is medium-light gray to medium-dark-gray, weathering light gray; contains skeletal fragments, sparry cements, and argillaceous material; grainstones; thin to medium beds; continuous, planar bedding; abundant bryozoans and brachiopods. Shale beds are of two types. Dominant type is medium gray (N5), weathering yellowish gray; calcareous; fossiliferous; mudshales; thin to medium beds; discontinuous, wavy to irregular-bedding; fissile-partings. Minor type is medium gray, weathering yellowish gray; calcareous; silty; sparsely fossiliferous; mudshales to clayshales; thin beds, continuous, planar- to irregular-bedding; platy-partings. Contact with the Arnheim formation is sharp.	7.9
Arnheim formation (informal unit) (incomplete): Limestone (53%) interbedded with shale (47%). Limestone beds are medium-light-gray to medium-dark-gray, weathering moderate-yellowish-brown (10 YR 5/4); contain skeletal fragments, sparry cements, and argillaceous material; grainstones; thin to thick beds; continuous, irregular- to planar-bedding; abundant brachiopods. Shale beds are olive gray (5 Y 6/1), weathering yellowish gray; calcareous; silty; sparsely fossiliferous; mudshales to clayshales; thin to medium beds; continuous, irregular- to planar-bedding; platy- to flaggy-partings.	1.2