Lithostratigraphy of Upper Ordovician Strata Exposed in Kentucky

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1151–E

Prepared in cooperation with the Commonwealth of Kentucky, University of Kentucky, Kentucky Geological Survey

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By G. W. Weir, W. L. Peterson, *and* W C Swadley

With a section on Biostratigraphy

By JOHN POJETA, JR.

CONTRIBUTIONS TO THE GEOLOGY OF KENTUCKY

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Descriptions of Upper Ordovician formations exposed in Kentucky, with a discussion of facies relations, environments of deposition, and paleogeography

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1984

DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Library of Congress Cataloging in Publication data

Weir, Gordon Whitney, 1922–
Lithostratigraphy of Upper Ordovician strata exposed in Kentucky.

(Contributions to the geology of Kentucky) (Geological Survey professional paper 1151–E)
Bibliography: p.
Includes index.
Supt. of Docs. no.: I 19.16:1151–E
1. Geology, stratigraphic—Ordovician. 2. Geology—Kentucky. I. Peterson, Warren Lee, 1925– . II. Swadley, W C. III. Title. IV. Series: Contributions to the geology of Kentucky. V. Series: United States. Geological Survey. Professional Paper 1151–E.
QE660.W45 1984 551.7'31'09769 84–600061

For sale by the Distribution Branch, Text Products Section,
U.S. Geological Survey, 604 South Pickett St., Alexandria, VA 22304

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LITHOSTRATIGRAPHY OF UPPER ORDOVICIAN STRATA EXPOSED IN KENTUCKY

By G. W. WEIR, W. L. PETERSON, and W C SWADLEY

ABSTRACT

Ordovician formations above the Lexington Limestone crop out in the Blue Grass region of Kentucky and along the Cumberland River and its tributaries. The formations are all conformable and in places intertongue and intergrade.

The major Ordovician units above the Lexington Limestone in the Blue Grass region are: The Clays Ferry Formation, the Kope Formation, the Garrard Siltstone, the Fairview Formation, the Calloway Creek Limestone, the Grant Lake Limestone, the Ashlock Formation, the Bull Fork Formation, and the Drakes Formation. The Clays Ferry Formation is made up of subequal amounts of fossiliferous limestone and shale and minor siltstone; the Clays Ferry is as much as 300 ft thick and intertongues with the Lexington Limestone and the Kope Formation. The Kope Formation resembles the partly equivalent Clays Ferry but has a higher shale content (60-80 percent) and thicker layers of shale; the Kope, as much as 275 ft thick, is mostly restricted to the northern part of the State. The Garrard Siltstone, which consists of very calcitic siltstone and minor shale, overlies the Clays Ferry Formation in the southeastern part of the Blue Grass region; the Garrard, as much as 100 ft thick, feathers out into the upper part of the Clays Ferry in southern central and northern east-central Kentucky.

The Fairview Formation is characterized by even-bedded limestone interlayered with nearly equal amounts of shale and minor siltstone. The Fairview crops out in the northern part of the Blue Grass region, where it generally overlies the Kope Formation or the Garrard Siltstone; it grades southward into the Calloway Creek Limestone. The Calloway Creek contains more limestone (generally at least 70 percent) and is more irregularly and thinner bedded than the Fairview.

The Grant Lake Limestone is composed of nodular-bedded limestone (70-90 percent), interlayered and intermixed with shale; it overlies the Fairview Formation in the northern part of the Blue Grass region and the Calloway Creek Limestone in the western and central parts. In east-central Kentucky, the Grant Lake is classified as a member of the Ashlock Formation, an assemblage of lithologically distinct units that were combined to facilitate mapping in the southeastern and southern part of the region. The Ashlock consists of the following members, in ascending order: The Tate (calcitic and dolomitic mudstone), the Grant Lake, the Gilbert (micrograined limestone and shale), the Stingy Creek (nodular-bedded mudstone and limestone), the Terrill (dolomitic and calcitic mudstone), the Sunset (micrograined limestone), and the Reba (nodular-bedded limestone and shale).

The Bull Fork Formation, which overlies the Grant Lake Limestone, is made up of subequal amounts of thin-bedded highly fossiliferous limestone and shale; limestone makes up about 80 percent of the basal part of the formation and decreases in abundance irregularly upward to only 20 percent of the top part. On the east side of the Blue Grass region, the Bull Fork grades into the Reba Member of the Ashlock Formation; on the west side, it grades into the Grant Lake.

The uppermost formation in the region is the Drakes Formation, which in east-central Kentucky consists of the Rowland Member (calcitic to dolomitic mudstone) overlain by the Preachersville Member (dolomitic to calcitic mudstone and dolomite and dolomitic siltstone). In northeast Kentucky, the Drakes is represented by only the Preachersville Member. In most of central and north-central Kentucky, the formation consists of three members: the Rowland at the base (dolomitic mudstone to muddy limestone), the Bardstown (fossiliferous limestone and shale), and the Saluda Dolomite (dolomite, in part calcitic and muddy). In northern north-central Kentucky, the Drakes is represented by only the Saluda Dolomite Member.

The top of the Ordovician sequence in the Blue Grass region is generally formed by members of the Drakes Formation, which are overlain by strata of Silurian age. Paleontologic studies show the Ordovician-Silurian contact to be an unconformity, although evidence of pre-Silurian erosion is inconspicuous. A pre-Devonian unconformity cuts deepest into the Ordovician section in southwestern central Kentucky, where locally the Drakes Formation and most of the Ashlock Formation have been removed. In this part of the region, rocks of Devonian age rest on the unconformity, which in a few places is angular and has a maximum discordance of about 4°.

The Ordovician formations that crop out in the Cumberland River region are, in ascending order: The Catheys(?) Formation (limestone and dolomitic limestone interbedded with shale), the Leipers Limestone (nodular-bedded limestone, calcarenite, and shale), and the Cumberland Formation (dolomite and dolomitic mudstone). The Cumberland is everywhere truncated and in places cut out by an early Paleozoic unconformity. Over most of its extent, the Cumberland is overlain by rocks of Devonian age, but locally in western south-central Kentucky it is overlain by rocks of Silurian age.

Fossils collected from Upper Ordovician formations cropping out in Kentucky, Ohio, and Indiana include brachiopods, bryozoans, gastropods, pelecypods, corals, stromatoporoids, trilobites, crinoids, ostracodes, and conodonts. Study of these fossils, especially the bryozoans and conodonts, shows that the basal part of the Clays Ferry Formation is locally of Middle Ordovician age. The bulk of the Clays Ferry and all the other formations described in this report are Late

Ordovician; they include strata forming outcrops in the type area of the Cincinnatian Provincial Series, a provincial time-rock division that has been widely applied by many workers to Upper Ordovician rocks in North America. This series has been divided on the basis of megafossils into three stages, in ascending order: Edenian, Maysvillian, and Richmondian. Studies of the conodont biostratigraphy indicate that most of the formations in Kentucky are markedly time transgressive.

The Upper Ordovician strata of Kentucky are divided into 14 lithofacies, generalized intergrading rock units differentiated by bulk composition, texture, bedding, and relative abundance of fossils. At many localities, the named formations and members are mostly made up of a single lithofacies or a few closely related lithofacies, although in some parts of the study area the formal units are composed of unrelated lithofacies. The lithofacies are assembled into four groups. Group I lithofacies are characterized by planar beds of fossiliferous limestone and shale, which were deposited in environments of fluctuating energy in waters probably ranging in depth from about 10 to 100 ft. Group II lithofacies are characterized by nodular beds of limestone, deposited in wave-agitated shallow waters probably ranging from about 3 to 50 ft in depth. Group III is a miscellaneous assemblage of lithofacies characterized by units of siltstone or limestone of uniform grain size, mostly deposited in shoals and lagoons of very shallow depth. Group IV lithofacies are dolomitic and were laid down in supratidal and high intertidal environments.

During the Late Ordovician, an epeiric sea occupied most of the eastern interior of the United States. The sea became shallower generally eastward toward lands along the margin of the continent. Two major features of the region in Lexington time—the miogeosyncline lying near the eastern borderlands and an ancestral Mississippi embayment—were effaced by early Cincinnatian time, in part by infilling with land-derived sediment. The post-Lexington strata of Kentucky were deposited in tropical latitudes on a shelf that throughout most of the Cincinnatian sloped generally northward. Sedimentation during this time appears unaffected by the Cincinnati arch or other structural elements active intermittently in the Paleozoic. The initial deposits on the shelf were shale, limestone, and siltstone laid down in open marine waters of moderate depth. Later, the seas shallowed, and fossiliferous limestone and shale were deposited on the northern part of the shelf, while dolomitic mudstone and dolomite were deposited on the southern part. Near the close of the Ordovician, the seas withdrew irregularly northward and left dolomitic mudstone and dolomite covering most of the region.

INTRODUCTION

This report describes the stratigraphy of exposed Ordovician formations above the Lexington Limestone in Kentucky and interprets this stratigraphy in terms of its paleogeographic implications. The report centers on the physical relations of rock bodies and the paleoenvironmental significance of the contained lithofacies. It is a companion paper to Cressman's (1973c) report on the lithostratigraphy and depositional environments of the Lexington Limestone of central Kentucky.

Ordovician rocks crop out in Kentucky mainly in two areas (fig. 1). The larger area of outcrop, covering much of the middle of the State, forms the major part of the Blue Grass region of Kentucky; outcrops in this region are adjacent to outcrops of Ordovician rocks in southwestern Ohio and southeastern Indiana. The smaller area of fairly continuous outcrops of Ordovician rocks lies south of the Blue Grass region along the Cumberland River and its tributaries; these outcrops are continuous with outcrops of Ordovician rocks in Tennessee.

Figure 2 shows the Upper Ordovician section in several areas of the Blue Grass region of Kentucky. The named subdivisions are rock-stratigraphic units characterized by the presence of particular types of rocks in definite proportions. Because of intergrading and intertonguing of rock types, many formations and members have arbitrary vertical cutoffs, and certain members are assigned to different formations in different localities. The boundaries, extent, and relations of the formal units above the Lexington Limestone are discussed under the appropriate headings in the following text. The stratigraphy of the Lexington Limestone was discussed by Cressman (1973c), and salient aspects of the stratigraphy of the High Bridge Group were described by Cressman and Noger (1976). A lexicon summarizing and indexing by quadrangle the usage of geologic names of Ordovician age in Kentucky was prepared by Weir and Cressman (1978).

Studies of the Upper Ordovician rocks concurrent with the Kentucky mapping program were mostly concerned with relating the formal names to mappable rock-stratigraphic units and lithofacies. Results of these studies were reported by Weir and Greene (1965), Weir, Greene, and Simmons (1965), Peck (1966), Weir and Peck (1968), Peterson (1970), Weir (1970), Swadley, Luft, and Gibbons (1975), and Weir, Peterson, and Swadley (1979a).

This report is based primarily on information gained in mapping 7½-minute quadrangles covering the outcrops of Ordovician rocks in Kentucky. These quadrangles, mapped at a scale of 1:24,000 by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey, are located on figure 3 and referenced by index number to table 1, which lists the authors and dates of publication of the pertinent reports; these reports are listed in full in the section below entitled "References Cited." Because the stratigraphic studies summarized in this report are the work of many geologists, descriptions of stratigraphy in specific quadrangles commonly are not referenced to the author of a particular geologic map.

The mapping was supplemented by study of measured sections and drill cores (mostly filed at the core library of the Kentucky Geological Survey). Figure 4 shows the locations of the principal measured sections and the drill holes, excluding those listed by Cressman (1973c, p. 6-7), and table 2 lists the measured sections. Many of the principal measured sections are diagrammed in plates 1 through 5.

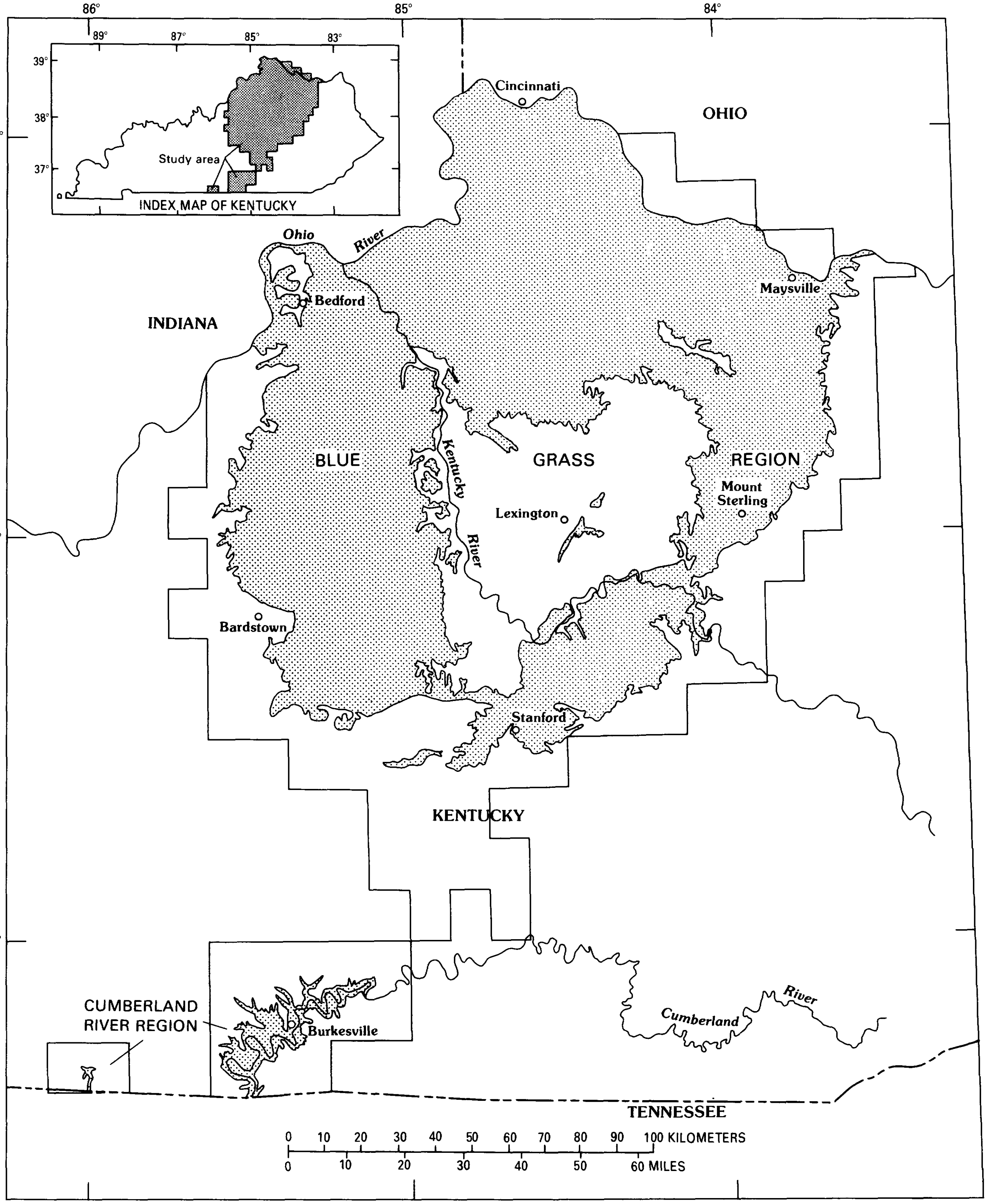

FIGURE 1.—Index map of Kentucky, showing outline of study area and generalized area of exposed Upper Ordovician rocks (shaded). Small areas of outcrops not shown.

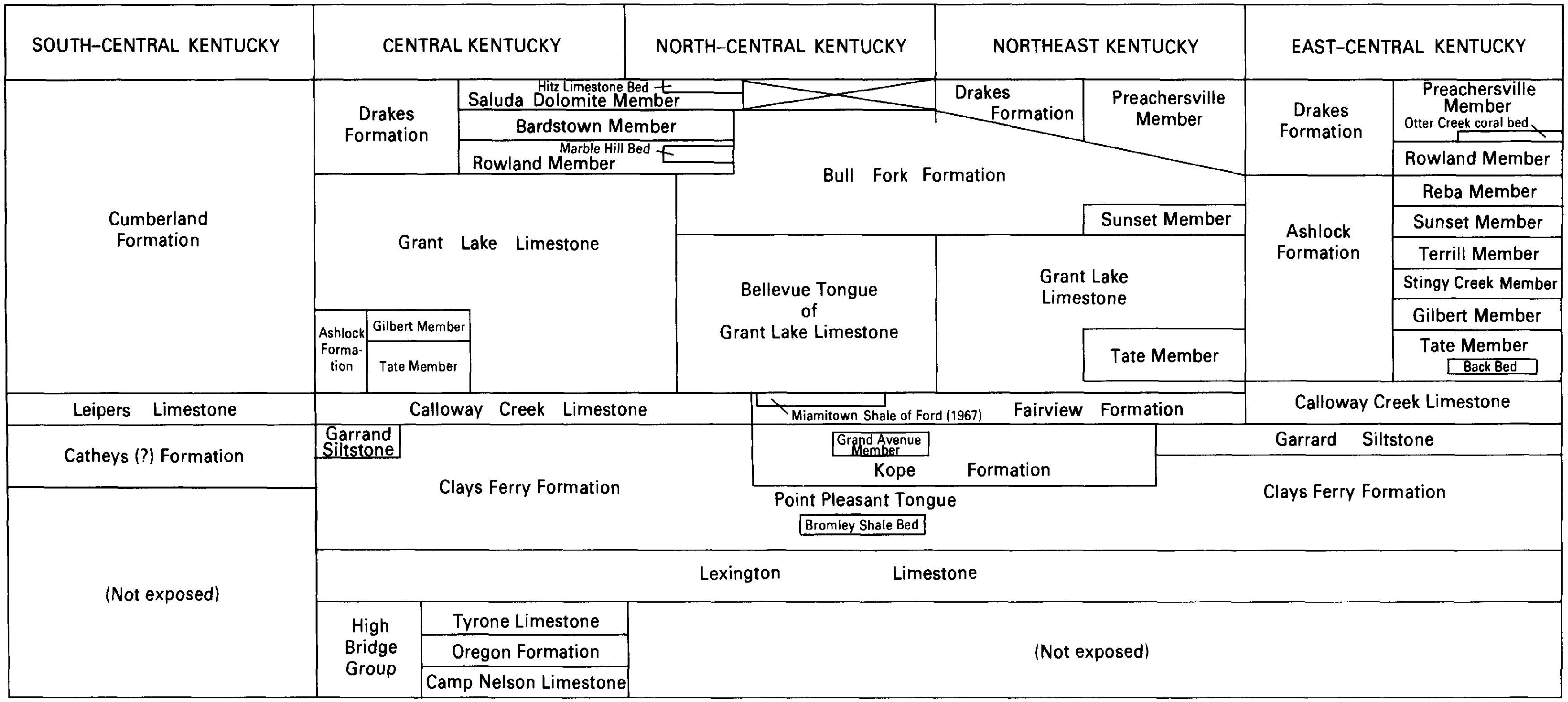

FIGURE 2.—Nomenclature of exposed rock-stratigraphic units of Ordovician age in Kentucky. Stratigraphic relations are approximate because effects of intergradation and variations in facies and thickness are not shown. No temporal relations implied. Not to scale.

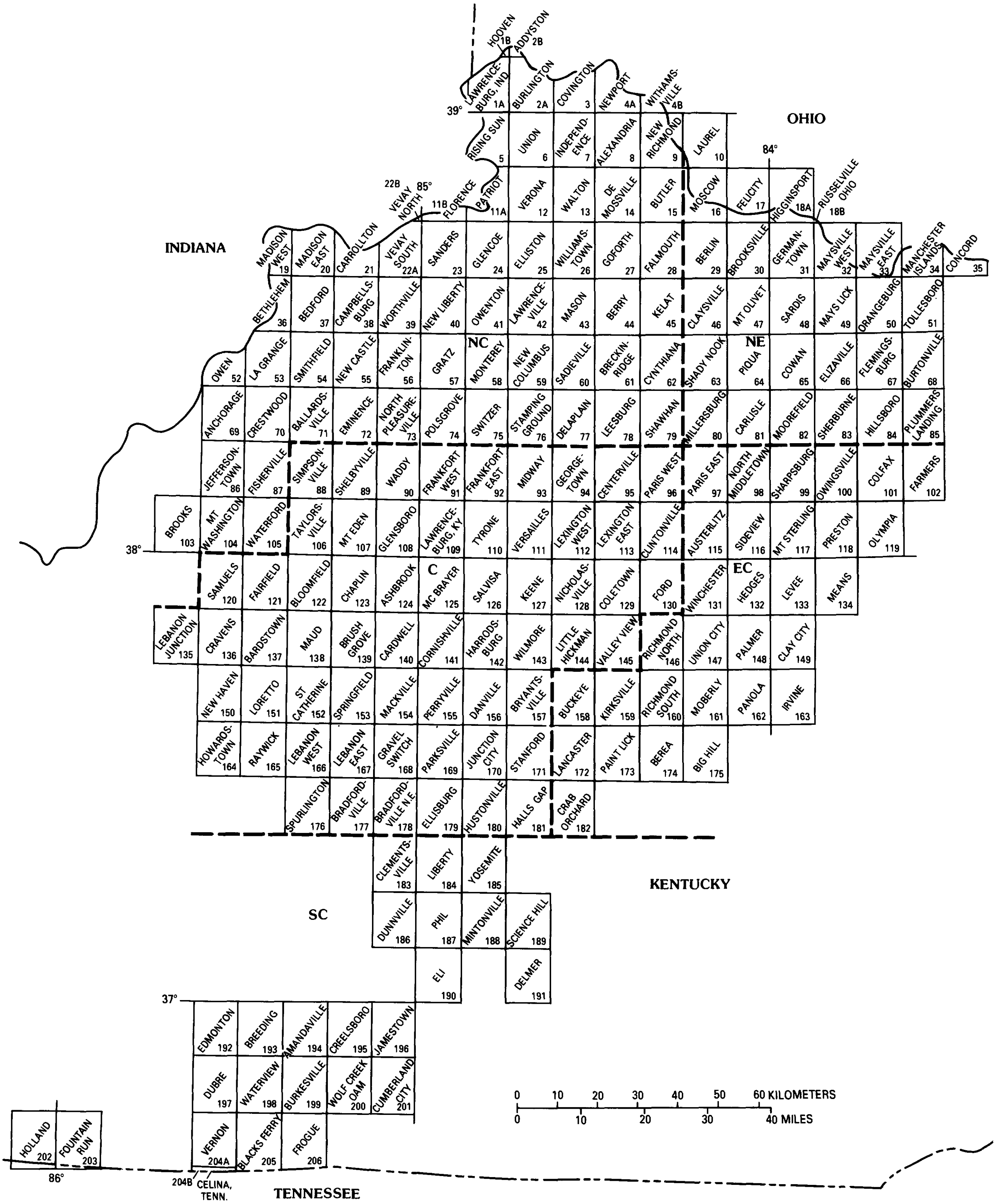

FIGURE 3.—Index of 7½-minute quadrangle maps in part of Kentucky, showing reference numbers and names of maps containing outcrops of Ordovician rocks, and delineating major divisions of the State (NC, north-central; NE, northeast; C, central; EC, east-central; SC, south-central) referred to in this report.

TABLE 1.—*Geologic quadrangle maps showing outcrops of Ordovician rocks in Kentucky*

Index No. (see fig. 3)	Quadrangle	Reference
2B	Addyston[1]-----------------	Gibbons (1972).
8	Alexandria----------------	Gibbons (1971).
194	Amandaville---------------	Taylor (1962).
69	Anchorage-----------------	Kepferle and others (1971).
124	Ashbrook------------------	Peterson (1976a).
115	Austerlitz----------------	Outerbridge (1975).
71	Ballardsville-------------	Kepferle (1977).
137	Bardstown-----------------	Peterson (1969).
37	Bedford-------------------	Swadley (1977a).
174	Berea---------------------	Weir (1967).
29	Berlin--------------------	Luft (1975a).
44	Berry---------------------	Luft (1975b).
36	Bethlehem[1]----------------	Swadley (1977b).
175	Bighill-------------------	Weir and others (1971).
205	Blacks Ferry--------------	Van Horn and Griffitts (1969).
122	Bloomfield----------------	Peterson (1973b).
177	Bradfordsville------------	Moore, S. L. (1977a).
178	Bradfordsville NE---------	Moore, S. L. (1977b).
61	Breckinridge--------------	Wallace (1976c).
193	Breeding------------------	Taylor (1964).
103	Brooks--------------------	Kepferle (1972).
30	Brooksville---------------	Outerbridge (1971a).
139	Brush Grove---------------	Peterson (1973a).
157	Bryantsville--------------	Wolcott and Cressman (1971).
158	Buckeye-------------------	Wolcott (1970).
199	Burkesville---------------	Cattermole (1963a).
2A	Burlington[1]---------------	Gibbons (1972).
68	Burtonville---------------	Morris (1965).
15	Butler--------------------	Luft (1972a).
38	Campbellsburg-------------	Swadley and Gibbons (1976).
140	Cardwell------------------	Peterson (1977b).
81	Carlisle------------------	Blade (1978a).
21	Carrollton[1]---------------	Swadley (1976).
204B	Celina[1]-------------------	Lewis (1972).
95	Centerville---------------	Kanizay and Cressman (1967).
123	Chaplin-------------------	Peterson (1975c).
149	Clay City-----------------	Simmons (1967d).
46	Claysville----------------	Luft (1976b).
183	Clementsville-------------	Taylor and Lewis (1972).
114	Clintonville--------------	MacQuown (1968a).
129	Coletown------------------	Black (1967).
101	Colfax--------------------	McDowell (1976).
35	Concord[1]------------------	Morris (1966).
141	Cornishville--------------	Cressman (1973b).
3	Covington[1]----------------	Luft (1971b).
65	Cowan---------------------	Blade (1978b).
182	Crab Orchard--------------	Gualtieri (1967).
136	Cravens-------------------	Peterson (1968).
195	Creelsboro----------------	Thaden and Lewis (1963).
70	Crestwood-----------------	Kepferle (1976c).
201	Cumberland City-----------	Lewis and Thaden (1965).
62	Cynthiana-----------------	Wallace (1976b).
156	Danville------------------	Cressman (1972a).
77	Delaplain-----------------	Wallace (1977c).
191	Delmer--------------------	Lewis (1971).
14	De Mossville--------------	Luft (1970).
197	Dubre---------------------	Lewis (1967b).
186	Dunnville-----------------	Maxwell (1965a).
192	Edmonton------------------	Cattermole (1966).
190	Eli-----------------------	Thaden and Lewis (1965).
66	Elizaville----------------	McDowell (1971).
179	Ellisburg-----------------	Moore, S. L. (1977c).
25	Elliston------------------	Swadley (1972b).
72	Eminence------------------	Luft (1977b).
121	Fairfield-----------------	Peterson (1975a).
28	Falmouth------------------	Luft (1972b).
102	Farmers-------------------	McDowell (1975).
17	Felicity------------------	Osborne and others (1973).
87	Fisherville---------------	Kepferle (1976b).
67	Flemingsburg--------------	Peck (1969).
11B	Florence[1]-----------------	Swadley (1969c).
130	Ford----------------------	Black (1968).
203	Fountain Run--------------	Hamilton (1963).
92	Frankfort East------------	Pomeroy (1968).
91	Frankfort West------------	Moore, F. B. (1975a).
56	Franklinton---------------	Gibbons (1976).
206	Frogue--------------------	Lewis (1967a).
94	Georgetown----------------	Cressman (1967).
31	Germantown----------------	Outerbridge (1971b).
24	Glencoe-------------------	Swadley (1974).
108	Glensboro-----------------	Cressman (1976b).
27	Goforth-------------------	Luft (1971a).
57	Gratz---------------------	Moore, F. B. (1977a).
168	Gravel Switch-------------	Moore, S. L. (1978b).
181	Halls Gap-----------------	Weir (1972).
142	Harrodsburg---------------	Allingham (1972).
132	Hedges--------------------	Black (1975).
18A	Higginsport---------------	Outerbridge and others (1973).
84	Hillsboro-----------------	Mytton and McDowell (1970).
202	Holland-------------------	Nelson (1962).
1B	Hooven[1]-------------------	Swadley (1972a).
164	Howardstown---------------	Kepferle (1966).
180	Hustonville---------------	Lewis and Taylor (1971).
7	Independence--------------	Luft (1969).
163	Irvine--------------------	Hoge and others (1976).
196	Jamestown-----------------	Thaden and Lewis (1962).
86	Jeffersontown-------------	Moore, F. B. and others (1972).
170	Junction City-------------	Harris (1972).
127	Keene---------------------	Cressman (1965).
45	Kelat---------------------	Luft (1974).
159	Kirksville----------------	Greene (1965).
53	La Grange[1]----------------	Peterson and others (1971).
172	Lancaster-----------------	Weir (1971).
10	Laurel--------------------	Kohut and others (1973).
109	Lawrenceburg (Ky.)--------	Cressman (1972b).
1A	Lawrenceburg (Ind.)[1]------	Swadley (1972a).

TABLE 1.—*Geologic quadrangle maps showing outcrops of Ordovician rocks in Kentucky*—Continued

Index No. (see fig. 3)	Quadrangle	Reference
42	Lawrenceville	Swadley (1975a).
167	Lebanon East	Moore, S. L. (1978c).
135	Lebanon Junction	Peterson (1967).
166	Lebanon West	Moore, S. L. (1978d).
78	Leesburg	Wallace (1976a).
133	Levee	McDowell (1978).
113	Lexington East	MacQuown and Dobrovolny (1968).
112	Lexington West	Miller (1967).
184	Liberty	Taylor and Lewis (1971b).
144	Little Hickman	Wolcott (1969).
151	Loretto	Peterson (1972a).
154	Mackville	Peterson (1977a).
20	Madison East[1]	Gibbons (1978).
19	Madison West[1]	Swadley (1978).
34	Manchester Islands[1]	Peck and Pierce (1966).
43	Mason	Luft (1976a).
138	Maud	Peterson (1972b).
49	Mays Lick	Gibbons (1968).
33	Maysville East	Weiss and others (1972).
32	Maysville West	Gibbons and Weiss (1972).
125	McBrayer	Cressman (1973a).
134	Means	Weir (1976a).
93	Midway	Pomeroy (1970).
80	Millersburg	Cuppels and Outerbridge (1974).
188	Mintonville	Lewis and Taylor (1974).
161	Moberly	Greene (1968a).
58	Monterey	Moore, F. B. (1977b).
82	Moorefield	Wigley (1978).
16	Moscow	Luft and others (1973).
107	Mount Eden	Cressman (1976a).
47	Mount Olivet	Wallace (1977a).
117	Mount Sterling	Weir (1976b).
104	Mount Washington	Kepferle (1976a).
55	New Castle	Gibbons (1977).
59	New Columbus	Moore, F. B. (1978).
150	New Haven	Peterson (1966).
40	New Liberty	Gibbons and Swadley (1976).
4A	Newport[1]	Gibbons (1973).
9	New Richmond	Gibbons and others (1975).
128	Nicholasville	MacQuown (1968b).
98	North Middletown	Helfrich (1977).
73	North Pleasureville	Peterson (1976b).
119	Olympia	McDowell and Weir (1977).
50	Orangeburg	Schilling and Peck (1967).
52	Owen[1]	Peterson and Wigley (1971).
41	Owenton	Swadley (1975b).
100	Owingsville	Weir (1975).
173	Paint Lick	Weir (1969).
148	Palmer	Simmons (1967c).
162	Panola	Greene (1968b).
97	Paris East	Outerbridge (1974b).
96	Paris West	Outerbridge (1974a).
169	Parksville	Moore, S. L. (1978a).
11A	Patriot[1]	Swadley (1969c).
152	Saint Catharine	Peterson (1975b).
126	Salvisa	Cressman (1968).
120	Samuels	Kepferle (1969).
23	Sanders	Swadley (1973a).
48	Sardis	McDowell (1973).
189	Science Hill	Taylor and Lewis (1973).
63	Shady Nook	Wallace (1975).
99	Sharpsburg	Blade (1977).
79	Shawhan	Cuppels (1973).
89	Shelbyville	Cressman (1975b).
83	Sherburne	Outerbridge (1970).
116	Sideview	Blade (1976).
88	Simpsonville	Peterson (1978).
54	Smithfield	Luft (1977a).
153	Springfield	Peterson (1977c).
176	Spurlington	Moore, S. L. (1974).
76	Stamping Ground	Moore, F. B. (1977c).
171	Stanford	Shawe and Wigley (1974).
75	Switzer	Moore, F. B. (1975b).
106	Taylorsville	Peterson (1977d).
155	Perryville	Cressman (1974).
187	Phil	Maxwell (1965b).
64	Piqua	Wallace (1977b).
85	Plummers Landing	McDowell and others (1971).
74	Polsgrove	Moore, F. B. (1976).
118	Preston	Weir and McDowell (1976).
165	Raywick	Kepferle (1973).
146	Richmond North	Simmons (1967a).
160	Richmond South	Greene (1966a).
5	Rising Sun[1]	Swadley (1971).
18B	Russelville[1]	Outerbridge and others (1973).
60	Sadieville	Moore, F. B., and Wallace (1978).
51	Tollesboro	Peck (1967).
110	Tyrone	Cressman (1964).
6	Union	Swadley (1969a).
147	Union City	Simmons (1967b).
145	Valley View	Greene (1966a).
204A	Vernon	Lewis (1972).
12	Verona	Swadley (1969b).
111	Versailles	Black (1964).
22B	Vevay North[1]	Swadley (1973b).
22A	Vevay South[1]	Swadley (1973b).
90	Waddy	Cressman (1975a).
13	Walton	Luft (1973a).
105	Waterford	Luft (1977c).
198	Waterview	Cattermole (1963b).
26	Williamstown	Luft (1973b).
143	Wilmore	Cressman and Hrabar (1970).
131	Winchester	Black (1974).
4B	Withamsville[1]	Gibbons (1973).
200	Wolf Creek Dam	Lewis and Thaden (1962).
39	Worthville	Gibbons (1975).
185	Yosemite	Taylor and Lewis (1971a).

[1]Only Kentucky part of quadrangle was mapped geologically.

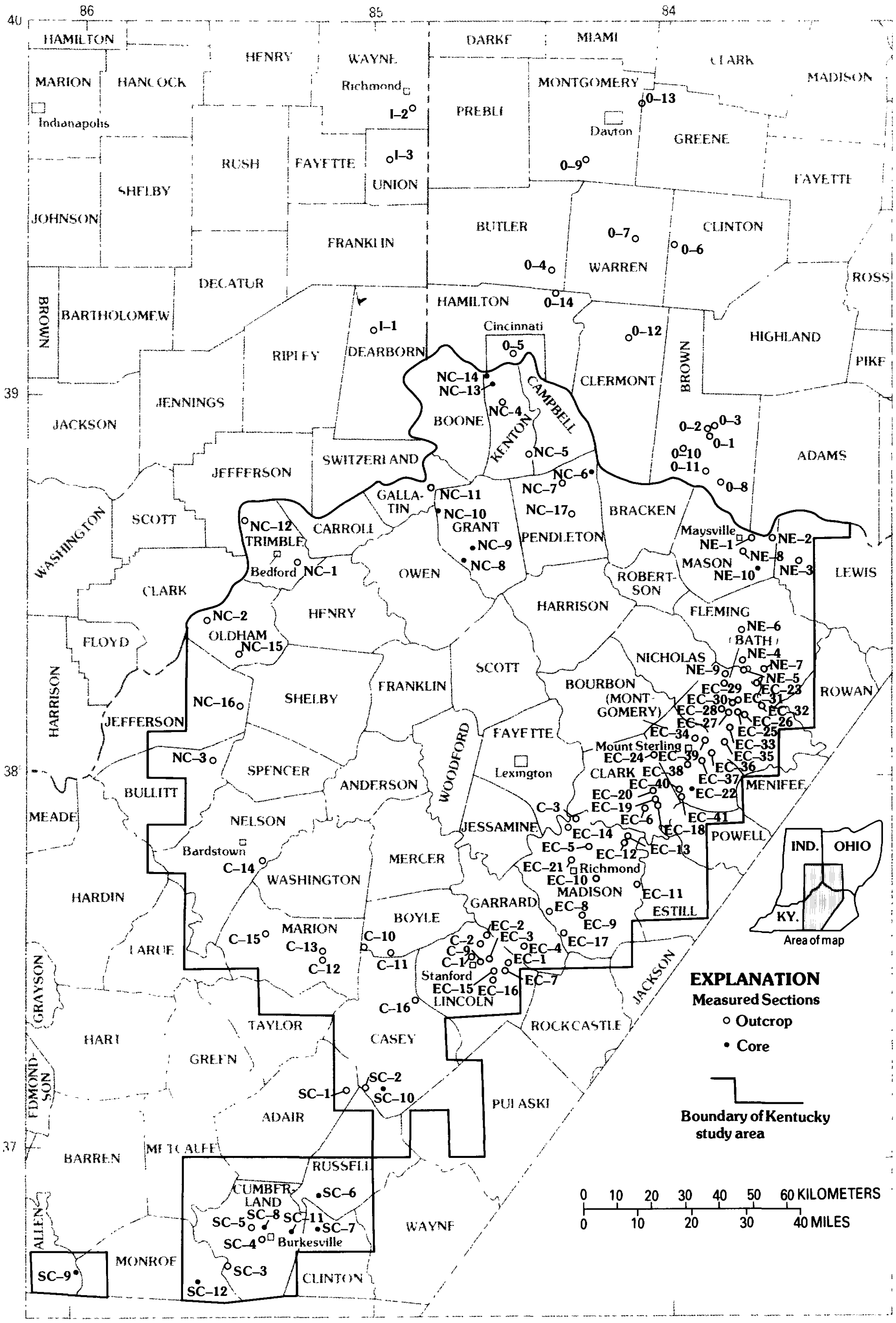

FIGURE 4.—Parts of Kentucky, Indiana, and Ohio showing counties and locations of measured sections. Measured section data are listed in table 2.

Locations in this report are mostly given in terms of individual quadrangles and parts of the divisions of Kentucky shown in figure 3. These divisions were devised during the mapping program for the whole State and are incorporated into the titles of many geologic quadrangle reports.

In addition to the authors, the following members of the U.S. Geological Survey participated in the measuring of sections and other stratigraphic studies that led to the present report: D. F. B. Black, L. V. Blade, P. E. Cassity, E. R. Cressman, A. B. Gibbons, R. C. Greene, J. L. Gualtieri, R. C. Kepferle, S. J. Luft, R. C. McDowell, J. H. Peck, F. A. Schilling, Jr., and G. C. Simmons.

The terminology in this report for megascopic descriptions of rocks is generally that used by Leighton and Pendexter (1962). The adjective "muddy" is applied to limestone and dolomite that contain a noticeable amount of clay and silt. The field term "mudstone" is retained in descriptions to denote rock containing a large admixture of clay and silt whose proportions are unknown. Most of the Upper Ordovician rocks described herein as "mudstone" are shown by chemical analysis (fig. 5) to be muddy calcitic dolomite, according to a classification modified from that of Leighton and Pendexter (1962, fig. 2). Most of the mudstone units are obscurely laminated or obscurely thin bedded. They generally lack shaly cleavage, although some weathered outcrops of mudstone yield platy fragments.

Megascopic descriptions of the rocks were supplemented by the examination of thin sections by W. L. Peterson. No attempt was made to study systematically the microscopic petrography of all units, but characteristics shown in thin sections of the most common rock types are described, using a terminology based on that of Folk (1962).

The weight percentages of insoluble residue and of calcite and dolomite (table 3) were determined for representative samples of carbonate rocks of most formations. Insoluble residues were obtained by leaching the crushed rock in warm hydrochloric acid. The weight percentages of dolomite and calcite were calculated from those of calcium and magnesium, which were determined by (1) analysis by atomic-absorption spectroscopy of the acid-soluble fraction obtained from the insoluble-residue determination, or (2) analysis by versene titration of a separate portion of the same rock sample from which the insoluble-residue determination was made. In calculating the calcite and dolomite percentages, all the magnesium was assumed to have been in dolomite, and all the calcium in calcite and dolomite. The results of these two procedures for determining calcium and magnesium are not strictly comparable, but given the assumptions involved in calculating the calcite and dolomite percentages, the differences are probably not significant.

GEOLOGIC SETTING

The chief structural feature of the study area is the Cincinnati arch, one of the major upwarps of the eastern interior of the United States. The axis of the arch nearly bisects the study area (fig. 6). The arch culminates in central Kentucky in the broad and irregular Jessamine dome. The high points on this dome, as contoured on the Tyrone Limestone of Middle Ordovician age, lie in the Little Hickman and Bryantsville quadrangles, southeastern central Kentucky (Black and others, 1976). The strata near the axis dip generally about 20 to 40 ft/mi to the east and west and about 10 to 20 ft/mi to the north and south. The uplift decreases toward the Tennessee State line, and then increases south of the study area to culminate in central Tennessee in the Nashville dome, a structure similar to the Jessamine dome.

The principal faults cutting the exposed Ordovician rocks in Kentucky are those of the east-northeast-trending Irvine-Paint Creek and Kentucky River fault systems, the Brumfield fault, and those of the north-northeast-trending Lexington fault system. The faults are normal, and most have displacements downward on the southeast. These major fault systems are probably controlled by deep-seated ancient fractures (Black and others, 1977). Not shown on the map (fig. 6) are many small normal faults that cut the northwest flank of the Jessamine dome. Many of these faults are in strata of Middle Ordovician age and form grabens that contain dolomitized rocks of Late Ordovician age.

The oldest exposed rocks in Kentucky are the limestone and dolomite of the High Bridge Group of Middle Ordovician age (Cressman and Noger, 1976). The High Bridge Group crops out in gorges of the Kentucky River and its tributaries where they cut the flanks of the Jessamine dome or intersect the Lexington or Kentucky River fault systems. Resting disconformably on the High Bridge Group is the Lexington Limestone of Middle and Late Ordovician age (Cressman, 1973c). The Lexington crops out extensively in the central part of the Blue Grass region, where it ranges in thickness from about 180 to 340 ft. The Lexington is divided into 12 members, most of which intertongue complexly with one another. It is conformably overlain by and in part intertongues and intergrades laterally with the Clays Ferry Formation of Middle and Late Ordovician age.

The Clays Ferry Formation and younger Ordovician formations in Kentucky form the chief subject of this report (fig. 2). This post-Lexington Ordovician sequence in Kentucky has not yet received a formal name. The equivalent sequence in adjoining Indiana is comprehended by the term "Maquoketa Group" as used by Gray (1972), and most of the sequence in northern Kentucky was included in the obsolescent Covington Group of Bassler (1906).

TABLE 2.—*Measured sections of Upper Ordovician formations in Kentucky, Indiana, and Ohio*

Section No.	Designation	Quadrangle	County	Coordinates at base of section	Formation	Measured by	Remarks and references
				KENTUCKY			
NE-1	Sleepy Hollow--------	Orangeburg, Maysville E.	Mason-------	E. 2,176,100, N. 410,450; north zone.	Fairview Formation, Grant Lake Limestone.	F. A. Schilling, Jr., and J. H. Peck.	Type section of Grant Lake Limestone (Peck, 1966, p. B22-B26).
NE-2	County Line----------	----do--------------	----do------	E. 2,176,500, N. 408,850; north zone.	Bull Fork Formation------	F. A. Schilling, Jr.; modified by J. H. Peck.	Type section of Bull Fork Formation (Peck, 1966, p. B26-B29).
NE-3	Tollesboro-----------	Tollesboro----------	Lewis-------	E. 2,202,900, N. 389,500; north zone.	Drakes Formation---------	F. A. Schilling, Jr. and J. H. Peck.	Weir, Peterson, and Swadley (1979c, p. 3-4).
NE-4	Locust South---------	Hillsboro-----------	Fleming-----	E. 2,150,200, N. 284,600; north zone.	Grant Lake Limestone, Bull Fork Formation.	----do----------------------	Weir, Peterson, and Swadley (1979c, p. 5-7).
NE-5	Indian Creek---------	----do--------------	Bath--------	E. 2,148,400, N. 273,950; north zone.	----do-------------------	----do----------------------	Weir, Peterson, and Swadley (1979c, p. 8-9).
NE-6	Carpenter Quarry-----	Flemingsburg--------	Fleming-----	E. 2,146,400 N. 320,450; north zone.	Grant Lake Limestone-----	----do----------------------	Weir, Peterson, and Swadley (1979c, p. 10-11).
NE-7	Hillsboro South------	Hillsboro-----------	----do------	E. 2,166,700, N. 281,600; north zone.	Drakes Formation---------	J. H. Peck and G. W. Weir---	Pipeline ditch (now covered). Weir, Peterson, and Swadley (1979c, p. 12-13).
NE-8	Maysville South------	Orangeburg----------	Mason-------	E. 2,146,400, N. 403,500; north zone.	Bull Fork Formation------	G. W. Weir and J. H. Peck---	Weir, Peterson, and Swadley (1979c, p. 14-17).
NE-9	Sherburne South------	Sherburne-----------	Bath--------	E. 2,131,750, N. 278,300; north zone.	Fairview Formation, Grant Lake Limestone, Bull Fork Formation.	J. H. Peck and G. W. Weir---	Weir, Peterson, and Swadley (1979c, p. 18-28).
NE-10	Dorcas Cooper No. 1 drill hole.	Orangeburg----------	Mason-------	E. 2,164,800, N. 379,500; north zone.	Grant Lake Limestone, Fairview Formation, Kope Formation.	G. W. Weir, W. L. Peterson, and W C Swadley.	Weir, Peterson, and Swadley (1979c, p. 29-30).
EC-1	Preachersville Southeast.	Lancaster-----------	Lincoln-----	E. 2,358,400, N. 427,300; south zone.	Drakes Formation---------	G. W. Weir------------------	Type section of Preachersville Member of the Drakes Formation (Weir and others, 1965, p. D33-D35).
EC-2	Ashlock Cemetery-----	----do--------------	----do------	E. 2,328,800, N. 452,550; south zone.	Ashlock Formation--------	G. W. Weir and R. C. Greene.	Type section of the Ashlock Formation and of Gilbert and Stingy Creek Members and of Back Bed of Tate Member (Weir and others, 1965, p. D24-D27).

EC-3	Walnut Flat Creek----	----do--------------	----do------	E. 2,336,400, N. 429,200; south zone.	Drakes Formation---------	G. W. Weir------------------	Weir, Peterson, and Swadley (1979c, p. 3-8).
EC-4	East Fork of Drakes Creek.	Paint Lick----------	Garrard-----	E. 2,363,300, N. 440,200; south zone.	----do-------------------	----do----------------------	Type section of the Drakes Formation (Weir and others, 1965, p. D30-D31).
EC-5	Otter Creek----------	Richmond North------	Madison-----	E. 2,426,600, N. 547,800; south zone.	Ashlock Formation, Drakes Formation.	G. C. Simmons and R. C. Greene.	Weir, Peterson, and Swadley (1979c, p. 9-12).
EC-6	Agawam South---------	Hedges--------------	Clark-------	E. 2,046,900, N. 151,000; north zone.	----do-------------------	G. W. Weir------------------	Weir, Peterson, and Swadley (1979c, p. 13-26).
EC-7	Cedar Ridge Church Northeast.	Crab Orchard--------	Lincoln-----	E. 2,347,200, N. 425,000; south zone.	----do-------------------	J. L. Gualtieri-------------	Weir, Peterson, and Swadley (1979c, p. 27-29).
EC-8	Kinnard Cemetery-----	Kirksville----------	Madison-----	E. 2,390,900, N. 475,400; south zone.	Garrard Siltstone, Calloway Creek Limestone.	R. C. Greene and P. E. Cassity.	Weir, Peterson, and Swadley (1979d, p. 30-35).
EC-9	Dog Branch-----------	Richmond South------	----do------	E. 2,426,6D0, N. 475,5D0; south zone.	Ashlock Formation--------	R. C. Greene----------------	Weir, Peterson, and Swadley (1979d, p. 36-38).
EC-10	Lake Reba------------	Moberly-------------	----do------	E. 2,434,400, N. 516,100; south zone.	Ashlock Formation, Drakes Formation.	R. C. Greene and G. C. Simmons.	Type section of Terrill and Reba Members of the Ashlock Formation (Weir and others, 1965, p. D27-D29).
EC-11	Drowning Creek-------	Panola--------------	----do------	E. 2,479,000, N. 508,700; south zone.	----do-------------------	R. C. Greene and J. C. Dills.	Weir, Peterson, and Swadley (1979d, p. 39-43).
EC-12	Clear Creek----------	Union City----------	----do------	E. 2,458,600, N. 548,000; south zone.	Ashlock Formation--------	G. C. Simmons and R. C. Greene.	Weir, Peterson, and Swadley (1979d, p. 44-47).
EC-13	Doylesville----------	----do--------------	----do------	E. 2,455,700, N. 534,750; south zone.	Drakes Formation---------	----do----------------------	Weir, Peterson, and Swadley (1979d, p. 48-49).
EC-14	Calloway Creek-------	Richmond North, Ford.	----do------	E. 1,975,200, N. 138,600; north zone.	Garrard Siltstone, Calloway Creek Limestone.	G. C. Simmons and P. E. Cassity.	Type section of Calloway Creek Limestone and reference section of Garrard Siltstone (Weir and others, 1965, p. D20-D22).
EC-15	Walnut Flat Southwest.	Crab Orchard--------	Lincoln-----	E. 2,338,000, N. 422,000; south zone.	Ashlock Formation--------	J. L. Gualtieri-------------	Weir, Peterson, and Swadley (1979d, p. 50).
EC-16	Walnut Flat South----	----do--------------	----do------	E. 2,339,600, N. 422,600; south zone.	Drakes Formation---------	----do----------------------	Weir, Peterson, and Swadley (1979d, p. 51-52).
EC-17	Wallaceton North-----	Berea---------------	Madison-----	E. 2,401,500 N. 457,000; south zone.	----do-------------------	G. W. Weir------------------	Weir, Peterson, and Swadley (1979d, p. 53-59).

TABLE 2.—*Measured sections of Upper Ordovician formations in Kentucky, Indiana, and Ohio*—Continued

Section No.	Designation	Quadrangle	County	Coordinates at base of section	Formation	Measured by	Remarks and references
KENTUCKY							
EC-18	Goffs Corner West	Hedges	Clark	E, 2,063,000, N. 160,000; north zone.	----do----	----do----	Weir, Peterson, and Swadley (1979d, p. 60-67).
EC-19	Crowe Ridge Road	----do----	----do----	E. 2,055,000, N. 163,000; north zone.	Calloway Creek Limestone, Ashlock Formation, Drakes Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 68-80).
EC-20	Pilot View Southeast.	----do----	----do----	E. 2,061,300, N. 160,500; north zone.	Ashlock Formation, Drakes Formation.	G. W. Weir and J. H. Peck	Weir, Peterson, and Swadley (1979d, p. 81-84).
EC-21	Arlington West	Richmond North	Madison	E. 2,414,000, N. 522,500; south zone.	Ashlock Formation	G. W. Weir	Weir, Peterson, and Swadley (1979d, p. 85-88).
EC-22	Cominco CA-35 core	Levee	Montgomery	E. 2,084,800, N. 163,200; north zone.	Calloway Creek Limestone, Ashlock Formation, Drakes Formation.	G. W. Weir, E. R. Cressman, and R. C. McDowell.	Weir, Peterson, and Swadley (1979d, p. 89-92).
EC-23	Oakla Southeast	Colfax	Bath	E. 2,152,800, N. 267,600; north zone.	Bull Fork Formation	J. H. Peck and G. W. Weir	Weir, Peterson, and Swadley (1979d, p. 93-94).
EC-24	Stoner Creek	Sideview	Clark	E. 2,052,600, N. 196,400; north zone.	Clays Ferry Formation, Kope Formation, Garrard Siltstone.	R. C. Greene and P. E. Cassity.	Weir, Peterson, and Swadley (1979d, p. 95-99).
EC-25	Owingsville West	Owingsville	Bath	E, 2,133,000, N. 234,100; north zone.	Bull Fork Formation, Drakes Formation.	G. W. Weir	Weir, Peterson, and Swadley (1979d, p. 100-107).
EC-26	Owingsville South	----do----	----do----	E. 2,140,000, N. 241,000; north zone.	Drakes Formation	----do----	Weir, Peterson, and Swadley (1979d, p. 108-111).
EC-27	Hurricane Creek East.	----do----	----do----	E. 2,129,400, N. 234,000; north zone.	Grant Lake Limestone, Bull Fork Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 112-118).
EC-28	Hurricane Creek West.	----do----	----do----	E. 2,123,000, N. 235,600; north zone.	Bull Fork Formation	----do----	Weir, Peterson, and Swadley (1979d, p. 119-127).
E-29	Bethel East	----do----	----do----	E. 2,115,400, N. 266,900; north zone.	Garrard Siltstone, Fairview Formation, Grant Lake Limestone, Bull Fork Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 128-144).
EC-30	Owingsville Northwest A.	----do----	----do----	E. 2,134,800, N. 241,200; north zone.	Grant Lake Limestone, Bull Fork Formation.	J. H. Peck and G. W. Weir	Weir, Peterson, and Swadley (1979d, p. 145-148).

EC-31	Owingsville Northwest B.	----do----	----do----	E. 2,135,500, N. 243,000; north zone.	Bull Fork Formation, Drakes Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 149-152).
EC-32	Rose Run----	Colfax----	----do----	E. 2,151,800, N. 233,400; north zone.	----do----	G. W. Weir----	Weir, Peterson, and Swadley (1979d, p. 153-158).
EC-33	Sugar Grove Church Northwest.	Preston----	----do----	E. 2,126,800, N. 222,800; north zone.	----do----	----do----	Weir, Peterson, and Swadley (1979d, p. 159-167).
EC-34	Hinkston Creek----	Mount Sterling----	Montgomery--	E. 2,094,100, N. 213,800; north zone.	Calloway Creek Limestone, Ashlock Formation.	R. C. Greene and P. E. Cassity.	Weir, Peterson, and Swadley (1979d, p. 168-170).
EC-35	Howards Mill----	Preston----	----do----	E. 2,118,800, N. 205,400; north zone.	Grant Lake Limestone, Bull Fork Formation, Drakes Formation.	J. H. Peck and G. W. Weir---	Weir, Peterson, and Swadley (1979d, p. 171-178).
EC-36	Spencer Creek----	Mount Sterling and Preston.	----do----	E. 2,107,900, N. 193,000; north zone.	Ashlock Formation, Bull Fork Formation, Drakes Formation.	G. W. Weir----	Weir, Peterson, and Swadley (1979d, p. 179-181).
EC-37	Greenbrier Road----	Mount Sterling----	----do----	E. 2,103,300, N. 187,200; north zone.	----do----	----do----	Weir, Peterson, and Swadley (1979d, p. 182-184).
EC-38	Head of Lulbegrud Creek.	----do----	----do----	E. 2,087,500, N. 185,700; north zone.	Ashlock Formation, Drakes Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 185-186).
EC-39	Ewington Southeast---	----do----	----do----	E. 2,106,100, N. 209,000; north zone.	Ashlock Formation, Bull Fork Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 187-188).
EC-40	Kiddville North----	Levee----	----do----	E. 2,075,600, N. 172,500; north zone.	Ashlock Formation, Drakes Formation.	----do----	Weir, Peterson, and Swadley (1979d, p. 189-190).
EC-41	Kiddville Northeast.	----do----	----do----	E. 2,076,400, N. 170,000; north zone.	----do----	----do----	Weir, Peterson, and Swadley (1979d, p. 191-192).
SC-1	Damron Creek----	Dunnville----	Adair----	E. 2,194,000, N. 309,400; south zone.	----do----	----do----	Weir, Peterson, and Swadley (1979b, p. 3-7).
SC-2	Dunnville South----	----do----	Casey----	E. 2,216,200, N. 309,600; south zone.	----do----	----do----	Weir, Peterson, and Swadley (1979b, p. 8-14).
SC-3	Judio North----	Blacks Ferry----	Cumberland--	E. 2,080,000, N. 137,500; south zone.	Catheys(?) Formation, Leipers Limestone, Cumberland Formation.	----do----	Weir, Peterson, and Swadley (1979b, p. 15-23).
SC-4	Burkesville----	Waterview----	----do----	E. 2,109,800, N. 164,200; south zone.	Cumberland Formation----	----do----	Weir, Peterson, and Swadley (1979b, p. 24-28).
SC-5	Grider Southeast----	----do----	----do----	E. 2,099,600, N. 169,200; south zone.	Leipers Limestone, Cumberland Formation.	----do----	Weir, Peterson, and Swadley (1979b, p. 29-35).

TABLE 2.—*Measured sections of Upper Ordovician formations in Kentucky, Indiana, and Ohio*—Continued

Section No.	Designation	Quadrangle	County	Coordinates at base of section	Formation	Measured by	Remarks and references
				KENTUCKY			
SC-6	Temple Hill Church No. 1 core.	Creelsboro----------	Russell-----	E. 2,178,900, N. 205,500; south zone.	Leipers Limestone, Clays Ferry(?) Formation.	G. W. Weir, W. L. Peterson, and W C Swadley.	Weir, Peterson, and Swadley (1979b, p. 36-38).
SC-7	William A. Connor No. 1 core.	Wolf Creek Dam------	Clinton-----	E. 2,151,100, N. 161,200; south zone.	Cumberland Formation, Leipers Limestone, Clays Ferry(?) Formation.	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 39-41).
SC-8	Herman Booher No. 1 core.	Burkesville---------	Cumberland--	E. 2,122,000, N. 174,100; south zone.	----do-------------------	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 42-44).
SC-9	St. Joseph Lead & Zinc Co. core.	Fountain Run--------	Allen(?)----	[Carter coordinates: 18-C-43].	Chattanooga Shale, Cumberland Formation, Leipers Limestone, Clays Ferry(?) Formation.	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 45-46).
SC-10	Thomas Ridge Church core.	Phil----------------	Casey-------	E. 2,227,200, N. 305,800; south zone.	Cumberland Formation, Leipers Limestone, Clays Ferry(?) Formation.	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 47-50).
SC-11	Cominco 12-D-51 core.	Burkesville---------	Cumberland--	[Carter coordinates: 12-D-51].	----do-------------------	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 51-52).
SC-12	Fred Thompson No. 1 core.	Vernon--------------	Monroe------	E. 2,042,800, N. 123,000; south zone.	----do-------------------	----do----------------------	Weir, Peterson, and Swadley (1979b, p. 53-54).
C-1	Rowland West---------	Stanford------------	Lincoln-----	E. 2,318,000, N. 436,500; south zone.	Drakes Formation---------	G. W. Weir------------------	Type section of Rowland Member of the Drakes Formation (Weir and others, 1965, p. D32-D33).
C-2	Ashlock Cemetery West.	----do--------------	----do------	E. 2,324,400, N. 455,000; south zone.	Ashlock Formation, Calloway Creek Limestone.	----do----------------------	Reference section of the Ashlock Formation (Weir and others, 1965, p. D23).
C-3	Clays Ferry----------	Ford----------------	Madison-----	E. 1,974,700, N. 139,500; north zone.	Clays Ferry Formation---	----do----------------------	Type section of the Clays Ferry Formation (Weir and Greene, 1965, p. B14-B17).
C-9	Rowland South--------	Stanford------------	Lincoln-----	E. 2,325,000, N. 427,000; south zone.	Drakes Formation---------	----do----------------------	Roadcuts (Weir, Peterson, and Kepferle, 1979, p. 3-5).
C-10	Hagan Hill Road------	Gravel Switch-------	Boyle-------	E. 2,207,200, N. 446,200; south zone.	Ashlock Formation, Drakes Formation.	----do----------------------	Weir, Peterson, and Kepferle (1979, p. 6-12).

C-11	Forkland East	Parksville	----do----	E. 2,231,200, N. 445,400; south zone.	Drakes Formation	----do----	Weir, Peterson, and Kepferle (1979, p. 13-16).
C-12	The Narrows North	Lebanon East	Marion	E. 2,179,400, N. 427,000; south zone.	Ashlock Formation, Drakes Formation.	----do----	Weir, Peterson, and Kepferle (1979, p. 17-22).
C-13	Wheeler Branch	----do----	----do----	E. 2,179,300, N. 429,000; south zone.	Drakes Formation	----do----	Weir, Peterson, and Kepferle (1979, p. 23-25).
C-14	Fredericktown	Maud	Nelson	E. 2,114,500, N. 521,600; south zone.	Drakes Formation, Ashlock Formation, Grant Lake Limestone.	W. L. Peterson and R. C. Kepferle.	Type section of Bardstown Member of the Drakes Formation (Peterson, 1970, p. A39-A41; Weir, Peterson, and Kepferle, 1979, p. 26-28).
C-15	Lebanon Quarry	Lebanon West	Marion	E. 2,121,500, N. 461,600; south zone.	Ashlock Formation	----do----	Weir, Peterson, and Kepferle (1979, p. 29-34).
C-16	Kidds Store	Hustonville	Casey	E. 2,260,300, N. 395,000; south zone.	----do----	G. W. Weir	Weir, Peterson, and Kepferle (1979, p. 35-40).
NC-1	Bedford East	Bedford	Trimble	E. 1,708,200, N. 404,800; north zone.	Drakes Formation, Bull Fork Formation, Grant Lake Limestone, Fairview Formation.	J. H. Peck, G. W. Weir, E. R. Cressman, and D. F. B. Black.	Weir, Swadley, and Peterson (1979, p. 3-15).
NC-2	Skylight South	Owen	Oldham	E. 1,634,900, N. 325,600; north zone.	Drakes Formation	G. W. Weir and W. L. Peterson.	Weir, Swadley, and Peterson (1979, p. 16-23).
NC-3	Mount Washington	Mount Washington	Bullitt	E. 1,624,000, N. 212,300; north zone.	----do----	W. L. Peterson and R. C. Kepferle.	Weir, Swadley, and Peterson (1979, p. 24-27).
NC-4	Narrows Road	Independence	Kenton	E. 1,905,600, N. 544,000; north zone.	Fairview Formation, Grant Lake Limestone.	S. J. Luft and A. B. Gibbons.	Weir, Swadley, and Peterson (1979, p. 28-32).
NC-5	Moffett Road	De Mossville	----do----	E. 1,958,400, N. 498,500; north zone.	Kope Formation, Fairview Formation, Clays Ferry Formation.	----do----	Weir, Swadley, and Peterson (1979, p. 33-45).
NC-6	Marble Cliff Quarry drill hole.	Butler	Pendleton	E. 1,998,740, N. 485,480; north zone.	Tyrone Limestone, Lexington Limestone.	A. B. Gibbons	Weir, Swadley, and Peterson (1979, p. 46-50).
NC-7	Geohegan and Mathis Quarry.	----do----	----do----	E. 1,973,000, N. 471,400; north zone.	Point Pleasant Member, Lexington Limestone.	A. B. Gibbons, S. J. Luft, and W C Swadley.	Weir, Swadley, and Peterson (1979, p. 51-57).
NC-8	Eagle Creek Dam Site, drill hole DC-3.	Lawrenceville	Grant	E. 1,877,000, N. 405,800; north zone.	Lexington Limestone, Clays Ferry Formation.	A. B. Gibbons, M. C. Noger, and W C Swadley.	Weir, Swadley, and Peterson (1979, p. 58-60).
NC-9	Eagle Creek Dam Site, drill hole DC-6.	----do----	----do----	E. 1,877,600, N. 406,000; north zone.	Point Pleasant Member of the Kope Formation.	W C Swadley and A. B. Gibbons.	Weir, Swadley, and Peterson (1979, p. 61-65).

TABLE 2.—*Measured sections of Upper Ordovician formations in Kentucky, Indiana, and Ohio*—Continued

Section No.	Designation	Quadrangle	County	Coordinates at base of section	Formation	Measured by	Remarks and references
				KENTUCKY			
NC-10	Franks drill hole----	Glencoe------------	----do------	E. 1,852,800, N. 447,000; north zone	Tyrone Limestone, Lexington Limestone, Clays Ferry Formation, Kope Formation.	A. B. Gibbons and H. C. Rainey III.	Weir Swadley, and Peterson (1979, p. 66-78).
NC-11	Big Sugar Creek Bridge.	Patriot------------	Gallatin----	E. 1,836,600, N. 466,600; north zone.	Clays Ferry Formation, Kope Formation.	A. B. Gibbons---------------	Weir, Swadley, and Peterson (1979, p. 79-82).
NC-12	Fisher Ridge Road----	Madison West--------	Trimble-----	E. 1,672,000, N. 430,900; north zone.	Drakes Formation, Bull Fork Formation.	W C Swadley-----------------	Weir, Swadley, and Peterson (1979, p. 83-85).
NC-13	Erlanger drill hole--	Covington-----------	Kenton------	E. 1,905,600, N. 563,200; north zone.	Clays Ferry Formation, Kope Formation, Fairview Formation, Grant Lake Limestone.	S. J. Luft and A. B. Gibbons.	Weir, Swadley, and Peterson (1979, p. 86-109).
NC-14	Constance drill hole.	----do-------------	Boone-------	E. 1,894,700, N. 563,200; north zone.	Tyrone Limestone, Lexington Limestone, Clays Ferry Formation, Kope Formation.	A. B. Gibbons, S. J. Luft, H. C. Rainey III, and W C Swadley.	Weir, Swadley, and Peterson (1979, p. 110-122).
NC-15	Crestwood quadrangle composite.	Crestwood-----------	Oldham------	--------------	Drakes Formation--------	R. C. Kepferle; modified by W C Swadley.	Compiled from map data.
NC-16	Fisherville quadrangle composite.	Fisherville---------	Jefferson---	--------------	Grant Lake Limestone, Drakes Formation.	R. C. Kepferle; modified by W C Swadley.	Do.
NC-17	Falmouth quadrangle composite.	Falmouth------------	Pendleton---	--------------	Clays Ferry Formation, Kope Formation, Fairview Formation.	S. J. Luft; modified by W C Swadley.	Do.
				INDIANA			
I-1	Tanners Creek--------	Guilford, Sunman----	Dearborn----	E. 715,200, N. 607,700; east zone.	Kope(?) Formation, Dillsboro Formation.	W. L. Peterson and R. C. Kepferle.	Weir, Peterson, and Swadley (1980, p. 3-6).
I-2	Elkhorn Creek--------	Richmond, New Paris.	Wayne-------	E. 710,500, N. 821,400; east zone.	Dillsboro(?) Formation, Whitewater Formation.	W. L. Peterson and G. W. Weir.	Weir, Peterson, and Swadley (1980, p. 7-15).
I-3	Liberty--------------	Liberty------------	Union-------	E. 701,900, N. 777,800; east zone.	Dillsboro(?) Formation---	----do---------------------	Weir, Peterson, and Swadley (1980, p. 16-18).

OHIO

O-1	Wells-Goecke Road----	Ash Ridge-----------	Brown-------	E. 1,617,600, N. 337,200; south zone.	Bull Fork(?) Formation---	G. W. Weir------------------	Weir, Peterson, and Swadley (1980, p. 19-23).
O-2	West Fork Road-------	----do--------------	----do------	E. 1,617,600, N. 339,300; south zone.	----do-------------------	----do----------------------	Weir, Peterson, and Swadley (1980, p. 24, 27).
O-3	Straight Creek-------	----do--------------	----do------	E. 1,619,600, N. 340,600; south zone.	----do-------------------	J. H. Peck and G. W. Weir---	Weir, Peterson, and Swadley (1980, p. 28-29).
O-4	Maud South-----------	Glendale------------	Butler------	E. 1,465,400, N. 494,500; south zone.	----do-------------------	G. W. Weir and E. R. Cressman.	Weir, Peterson, and Swadley (1980, p. 30-32).
O-5	Bellevue Hill Park---	Covington-----------	Hamilton----	E. 1,427,500, N. 413,700; south zone.	Kope Formation, Fairview Formation, Grant Lake Limestone, Bull Fork(?) Formation.	----do----------------------	Weir, Peterson, and Swadley (1980, p. 33-39).
O-6	Fort Ancient North---	Oregonia------------	Warren------	E. 1,546,200, N. 520,800; south zone.	Bull Fork Formation, Drakes(?) Formation.	G. W. Weir------------------	Weir, Peterson, and Swadley (1980, p. 40-46).
O-7	Stony Hollow---------	Clarksville---------	Clinton, Warren.	E. 1,578,700, N. 516,000; south zone.	Bull Fork Formation------	----do----------------------	Weir, Peterson, and Swadley (1980, p. 47-51).
O-8	Ripley North---------	Russelville---------	Brown-------	E. 1,624,500, N. 285,000; south zone.	Fairview Formation, Grant Lake Limestone.	J. H. Peck, G. W. Weir and W. L. Peterson.	Weir, Peterson, and Swadley (1980, p. 52-57).
O-9	Miamisburg-----------	Miamisburg----------	Montgomery--	E. 1,495,600, N. 601,000, south zone.	Bull Fork Formation------	G. W. Weir and W. L. Peterson.	Weir, Peterson, and Swadley (1980, p. 58-59).
O-10	Georgetown Northwest.	Hammersville, Higginsport.	Brown-------	E. 1,593,000, N. 321,700; south zone.	Kope Formation, Fairview Formation, Grant Lake Limestone, Bull Fork Formation.	J. H. Peck and G. W. Weir---	Weir, Peterson, and Swadley (1980, p. 60-64).
O-11	Dixon Ridge----------	Russellville--------	----do------	E. 1,609,800, N. 289,800; south zone.	Fairview Formation, Grant Lake Limestone.	----do----------------------	Weir, Peterson, and Swadley (1980, p. 65).
O-12	Stonelick Creek------	Goshen, Newtonville.	Clermont----	E. 1,534,400, N. 423,400; south zone.	Fairview Formation. Grant Lake Limestone, Bull Fork Formation.	----do----------------------	Weir, Peterson and Swadley (1980, p. 66-71).
O-13	Huffman Dam----------	Fairborn------------	Green-------	E. 1,553,000, N. 685,000; south zone.	Bull Fork Formation, Drakes Formation.	----do----------------------	Weir, Peterson, and Swadley (1980, p. 72-76).
O-14	Highpoint West-------	Mason, Glendale-----	Hamilton----	E. 1,469,400, N. 474,500; south zone.	Grant Lake Limestone, Bull Fork Formation.	G. W. Weir------------------	Weir, Peterson, and Swadley (1980, p. 77-79).

The top of the Ordovician sequence in Kentucky is formed by members of the Drakes Formation or by the Cumberland Formation, except near the axis of the Cincinnati arch where older formations are locally at the top of the sequence (fig. 7). The Ordovician strata in most of the study area are overlain by strata of Silurian age—the Brassfield Dolomite (Formation) or in a few localities, the Osgood Formation (fig. 8). Paleontologic studies show that the contact at the top of the Ordovician strata is an unconformity (Rexroad and others, 1965, p. 12; Rexroad, 1967, p. 15-16; C. B. Rexroad, in Gray and Boucot, 1972, p. 1301). Evidence of post-Ordovician, pre-Silurian erosion is generally inconspicuous, although rarely, as in places in north-central and east-central Kentucky, clasts derived from the underlying Ordovician strata are incorporated into basal beds of the Silurian (Weir, 1967; Gauri and others, 1969).

Near the axis of the Cincinnati arch, the Ordovician strata are unconformably overlain by the Boyle Dolomite of Middle Devonian age or by the New Albany Shale of Middle and Late Devonian age (fig. 8). The post-Ordovician unconformity cuts deepest into the section in the Stanford quadrangle, southwestern central Kentucky, where locally the Drakes Formation and

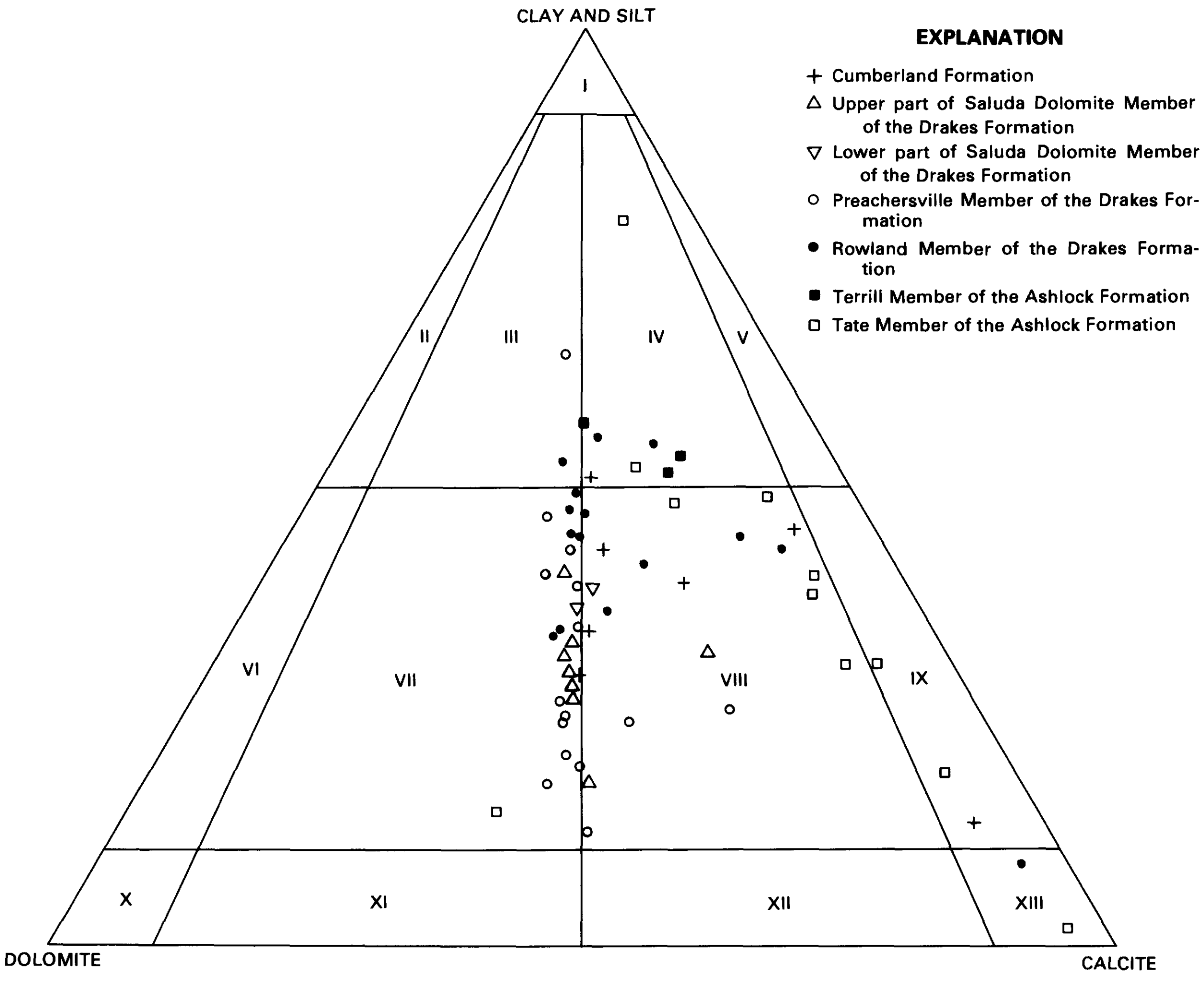

FIGURE 5.—Ternary diagram showing compositions of "mudstones" of this report. Classification modified from Leighton and Pendexter (1962, fig. 2). Divisions and names supplied for noncarbonate rocks (more than 50 percent clay and silt); modifiers supplied for impure carbonate rocks. I, mudstone; II, dolomitic mudstone; III, calcitic dolomitic mudstone; IV, dolomitic calcitic mudstone; V, calcitic mudstone; VI, muddy dolomite; VII, muddy calcitic dolomite; VIII, muddy dolomitic limestone; IX, muddy limestone; X, dolomite; XI, calcitic dolomite; XII, dolomitic limestone; XIII, limestone. Percentages of calcite, dolomite, and clay and silt calculated from analyses for elemental calcium and magnesium of representative mudstone samples from the Ashlock, Drakes, and Cumberland Formations; analyst, R. F. Gantnier.

most of the Ashlock Formation have been removed by erosion. The unconformity also cuts deeply into the Ordovician section near the Tennessee State line, as in the Blacks Ferry and Vernon quadrangles, where the Cumberland Formation and part of the Leipers Limestone have been removed. In a few places the unconformity is angular (Jillson, 1956, p. 69). The maximum discordance measured was about 4° in the Hustonville quadrangle, southwestern central Kentucky (fig. 9).

PREVIOUS NOMENCLATURE

Geologic mapping at the scale 1:24,000 in Kentucky showed the need for names for newly discriminated rock units of Ordovician age. This need in part arose from the greater detail permitted by the larger scale, because most previous geologic mapping in Kentucky was at the scale of 1:63,360 or smaller. In addition, many stratal divisions of the Ordovician used by earlier workers were based on fossil content rather than rock character.

Much of the previous nomenclature used in subdivisions of the Upper Ordovician in Kentucky was developed by stratigraphers working in southern Ohio and Indiana. The development of this nomenclature was reviewed by Gutstadt (1958, p. 518-521), Weiss and Norman (1960), Weiss (1961), and Fox (1962, p. 622-628), who pointed out the confusion between faunal and rock units. Later studies in these States, as in Kentucky, have led to the development of a nomenclature based on rock character (Weiss and Sweet, 1964; Brown and Lineback, 1966; Ford, 1967; Shaver and others, 1970, p. 45-48; Gray, 1972). Figure 10 shows representative sections of Upper Ordovician rocks in several areas in Kentucky and compares the current and previous nomenclatures applied to these sections.

Table 4 lists abandoned and little-used stratigraphic names formerly applied in Kentucky to exposed strata of Ordovician age above the Lexington Limestone. Not listed are a few present-day time-stratigraphic terms—such as Edenian, Maysvillian, and Richmondian, which were used without the adjectival suffix as formation and group names by Jillson (1929). These names were rarely applied to rock-stratigraphic units after the publication of correlation charts of the Ordovician System of North America by Twenhofel (1954).

Some stratigraphic names, such as "Utica Shale," were drawn from areas far outside Kentucky; application of these names in Kentucky commonly differed from that within the type area. Several names drawn from Kentucky localities, such as "Cynthiana Formation,"

TABLE 3.—*Insoluble residues and calculated calcite and dolomite content of representative samples of carbonate rocks from Upper Ordovician formations in Kentucky*

[Results in weight percent. Analysts: A. E. Childress and R. F. Gantnier]

Stratigraphic unit (rock type analyzed)	Number of samples	Insoluble residue lowest	Insoluble residue arithmetic mean	Insoluble residue highest	Calcite lowest	Calcite arithmetic mean	Calcite highest	Dolomite lowest	Dolomite arithmetic mean	Dolomite highest
Clays Ferry Formation (limestone)	22	3	11	25	61	83	93	2	4	16
Kope Formation (limestone)	6	2	6	13	83	92	97	2	3	4
Calloway Creek Limestone (limestone)	11	1	11	22	63	85	97	3	6	13
Fairview Formation (limestone)	3	6	12	23	74	84	89	2	4	5
Grant Lake Limestone										
(limestone)	10	3	7	24	64	85	92	4	10	11
(muddy limestone or calcitic shale)	4	38	44	48	15	25	36	20	23	30
Ashlock Formation:										
Gilbert Member (limestone)	5	3	8	12	85	89	96	3	5	8
Tate Member (muddy limestone or mudstone)	9	17	30	35	35	45	57	12	19	27
Bull Fork Formation (limestone)	7	3	8	24	71	88	94	2	3	6
Drakes Formation:										
Saluda Dolomite Member										
Hitz Limestone Bed (limestone)	3	4	7	9	46	69	91	6	23	41
Upper part (dolomite from the dolomite and calcitic dolomite lithofacies)	9	11	21	34	9	14	31	37	57	66
Lower part (muddy dolomite from the dolomitic mudstone and dolomite lithofacies)	3	31	33	36	9	11	13	48	52	55
Bardstown Member (limestone)	5	3	10	18	75	84	94	3	5	7
(muddy limestone)	6	25	35	45	12	26	57	15	33	51
Rowland Member (limestone from the dolomitic limestone and calcitic mudstone lithofacies)	4	14	17	18	64	70	81	3	12	16
(muddy limestone or mudstone from the dolomitic mudstone lithofacies)	6	21	35	45	10	23	41	17	31	48

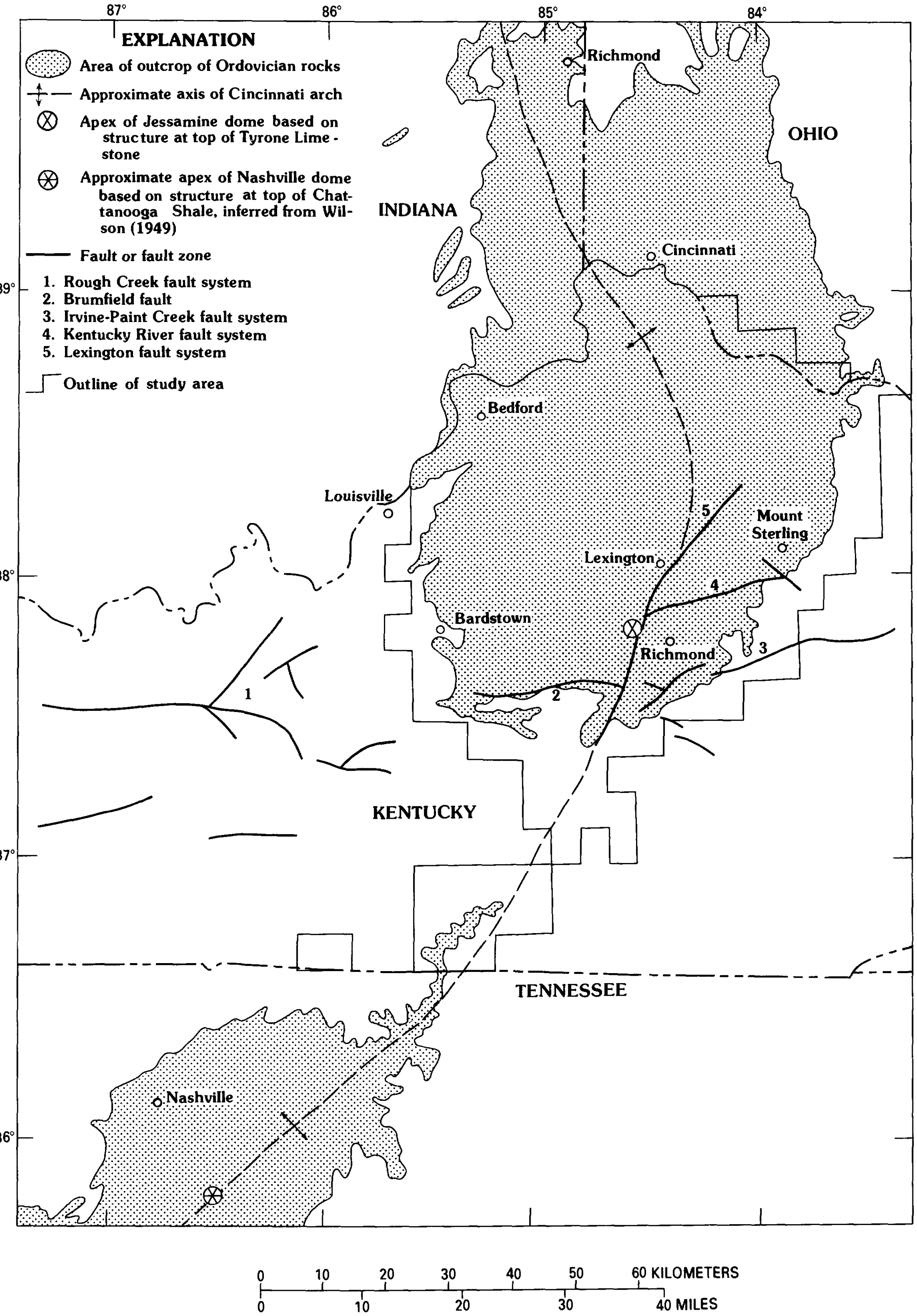

FIGURE 6.—Parts of Kentucky and adjacent States, showing outline of study area, area of outcrop of Ordovician rocks, and selected major structural features. Faults modified from U.S. Geological Survey and American Association of Petroleum Geologists (1962) and Black and others (1977); area of outcrop of Ordovician rocks from King and Beikman (1974).

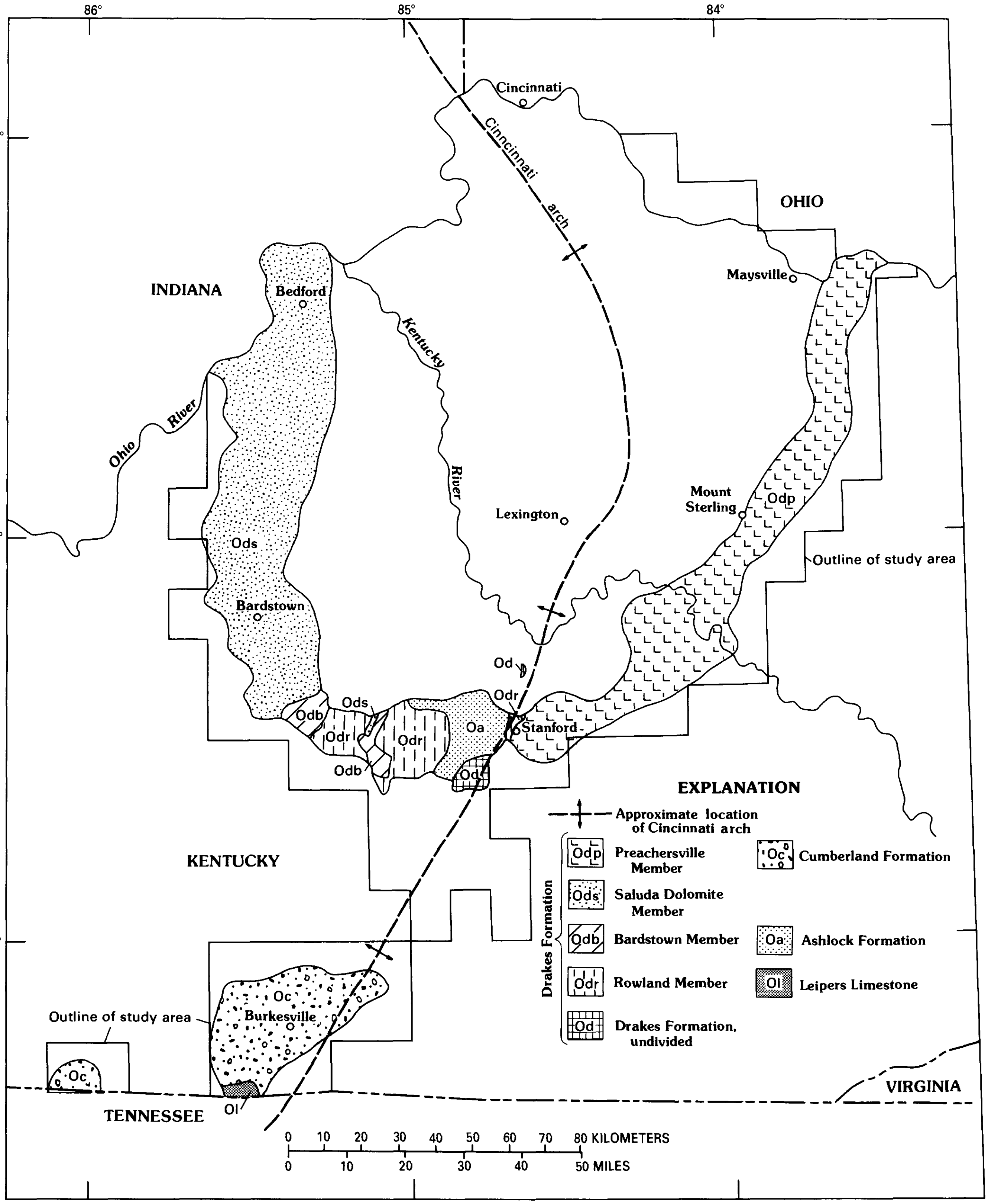

FIGURE 7.—Part of Kentucky, showing units at top of Ordovician sequence.

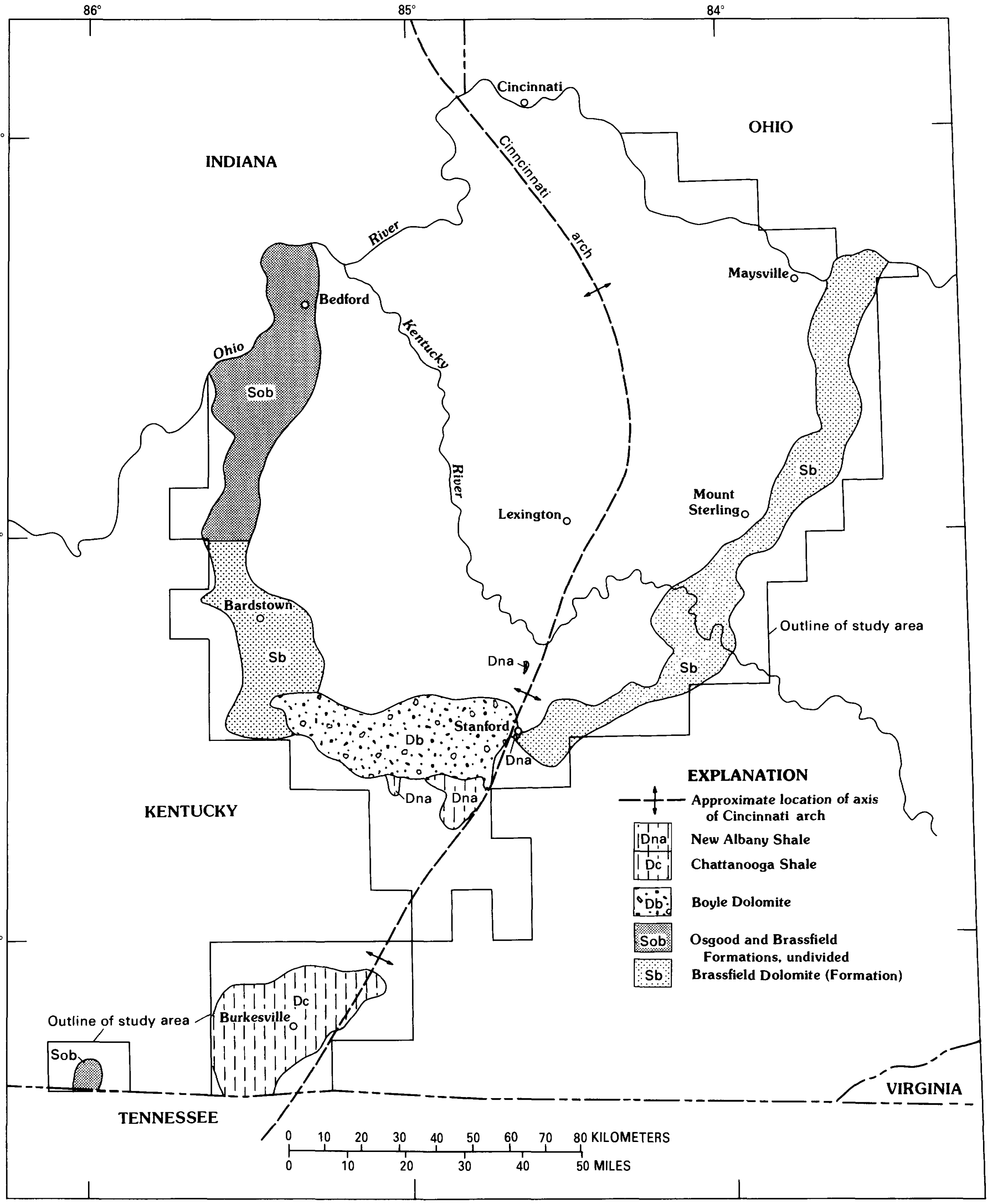

FIGURE 8.—Part of Kentucky, showing units lying on top of Ordovician sequence.

had divergent applications by different geologists. The citations for Kentucky usage (table 4) are, where possible, selected to describe the common usage tabulated by Palmquist and Hall (1961, pl. 1). A few names, however, such as the Rennix Limestone of Foerste (1901), apparently were used but once.

The interested reader will find the most complete description of the older stratigraphic units in McFarlan's (1943, p. 12-33) review of the Ordovician of Kentucky. The older nomenclature of the classic Cincinnatian section was summarized by Caster and others (1961). Table 4 gives an approximate idea of present-day formations containing strata formerly designated by the abandoned or obsolescent names. More detailed relations between the nomenclature used by earlier workers and the current nomenclature are shown on many of the Kentucky geologic quadrangle maps. Previous nomenclature was also compared with current usage in a lexicon of Ordovician rock-stratigraphic units in Kentucky (Weir and Cressman, 1978). Table 4 also cites, where possible, publications that note the history of each term.

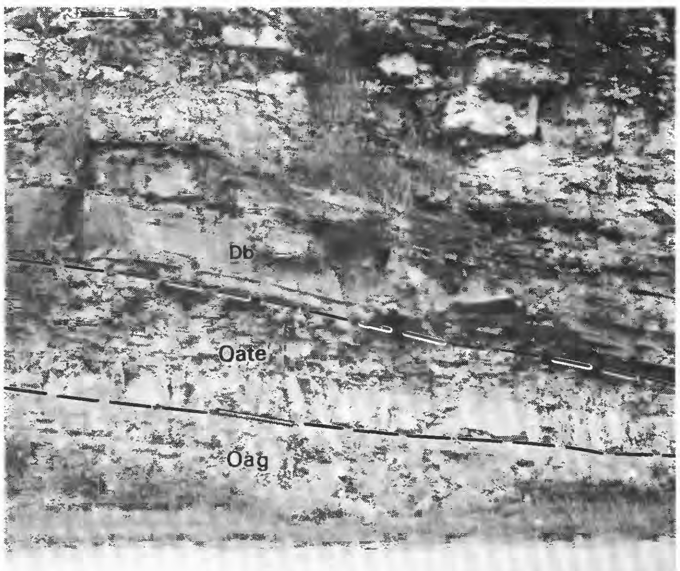

FIGURE 9.—Angular unconformity at top of Ordovician section in roadcut on U.S. Highway 127 near Kidds Store, Hustonville quadrangle, southeastern central Kentucky. Boyle Dolomite (Db) of Middle Devonian age rests with about 4° discordance on Terrill Member (Oate) of the Ashlock Formation; Gilbert Member (Oag) of the Ashlock is exposed at base. Note truncation of beds in Terrill toward right; Reba Member of the Ashlock and all of the Drakes Formation were cut out before the Boyle was deposited. Rod at contact between Terrill and Gilbert Members is 5 ft long.

STRATIGRAPHY

BLUE GRASS REGION

The Ordovician formations above the Lexington Limestone in the Blue Grass region are: The Clays Ferry Formation, the Kope Formation, the Garrard Siltstone, the Fairview Formation, the Calloway Creek Limestone, the Grant Lake Limestone, the Ashlock Formation, the Bull Fork Formation, and the Drakes Formation (fig. 2). Collectively, these formations cover much of the surface of north-central, northeast, east-central, and central Kentucky. In the following pages, they are discussed in approximate stratigraphic order from oldest to youngest, and in approximate geographic order of outcrop area from north to south.

CLAYS FERRY FORMATION

The type section of the Clays Ferry Formation, a major rock-stratigraphic unit in the Blue Grass region, crops out along and near Interstate Highway I-75 in the southern part of the Ford quadrangle, eastern central Kentucky (Black and MacQuown, 1965, p. 22; Weir and Greene, 1965, p. B14-B17).

LITHOLOGY

LIMESTONE

The Clays Ferry Formation is made up of subequal amounts of limestone and shale (30-60 percent each) and minor siltstone (5-10 percent). Most limestone is composed of whole and broken fossils in a micrograined or fine- to medium-grained matrix. Also common is micrograined limestone containing only sparse fossils. Locally common and conspicuous is coarse fossil-fragmental limestone composed of crinoid columnals or brachiopod shells. Some brachiopodal limestone consists almost wholly of a single genus—*Rafinesquina*, *Sowerbyella*, or *Dalmanella*—cemented by muddy micrograined calcite. The thin flat shells of *Rafinesquina* in some beds of brachiopodal limestone are jumbled, and in others stacked uniformly at high angles to the bedding. The limestone is mostly medium gray to olive gray and weathers the same or to lighter shades of gray. The fine- to medium-grained limestone is mostly in irregular to even, in part discontinuous beds, 2 to 10 in. thick, which are grouped in sets a few inches to a few feet thick. Coarse-grained limestone is in similar beds and also in trough sets, generally about 1 to 2 ft thick and 3 to 5 ft both wide and long, of low-angle thin crossbeds. Sparsely fossiliferous micrograined limestone is in persistent even beds, a few inches thick. Ripple marks are common; most are relatively straight and have amplitudes of a fraction of an

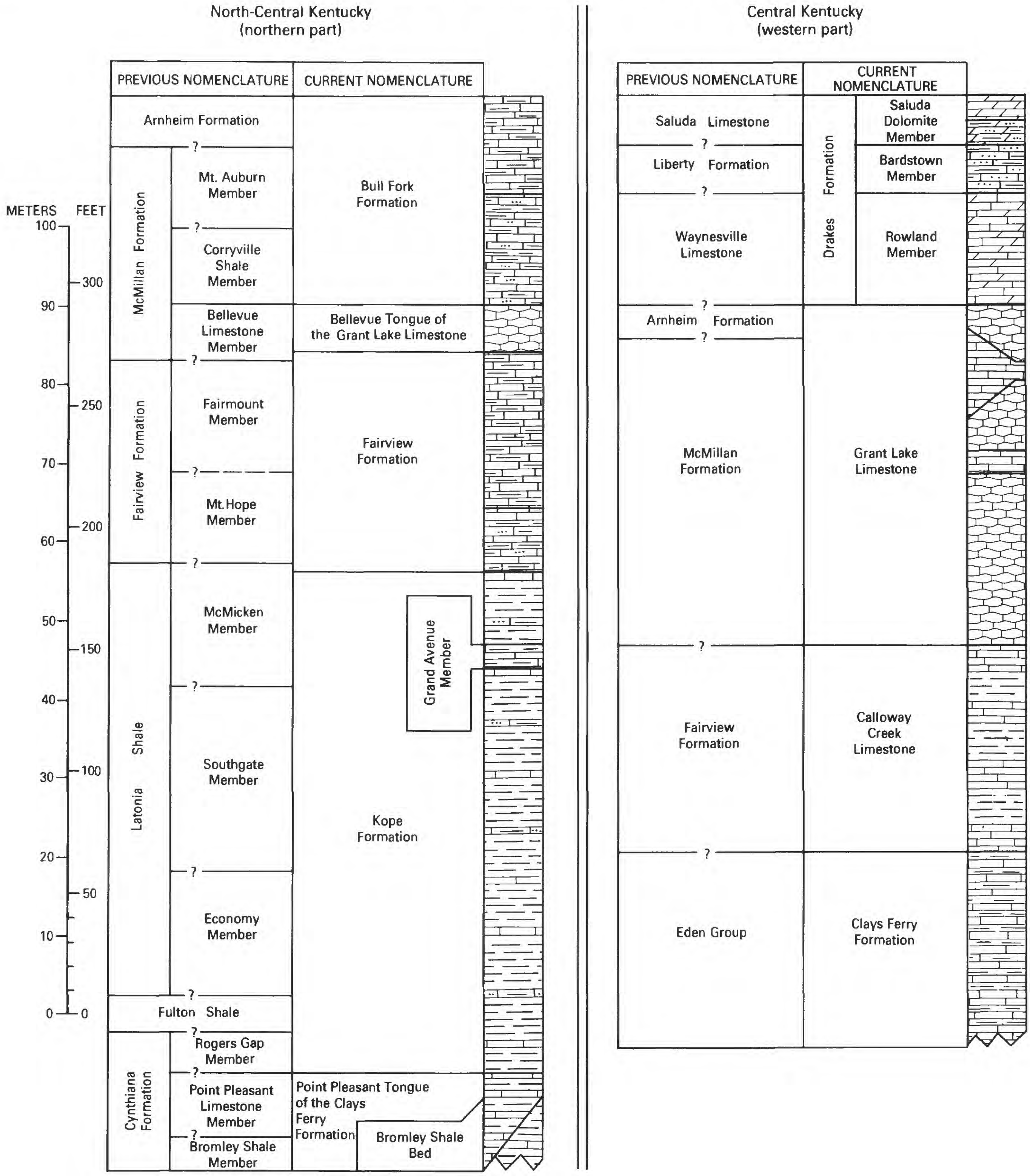

FIGURE 10.—Representative sections of Upper Ordovician rocks in Blue Grass region of Kentucky, comparing stratigraphic nomenclature used in this report and nomenclature used by Palmquist and Hall (1961) and other earlier workers. Equivalences are only approximate because of uncertainty about criteria used to limit older units. See plates 6 and 7 for lithologic relations and figure 50 for correlation of formal units.

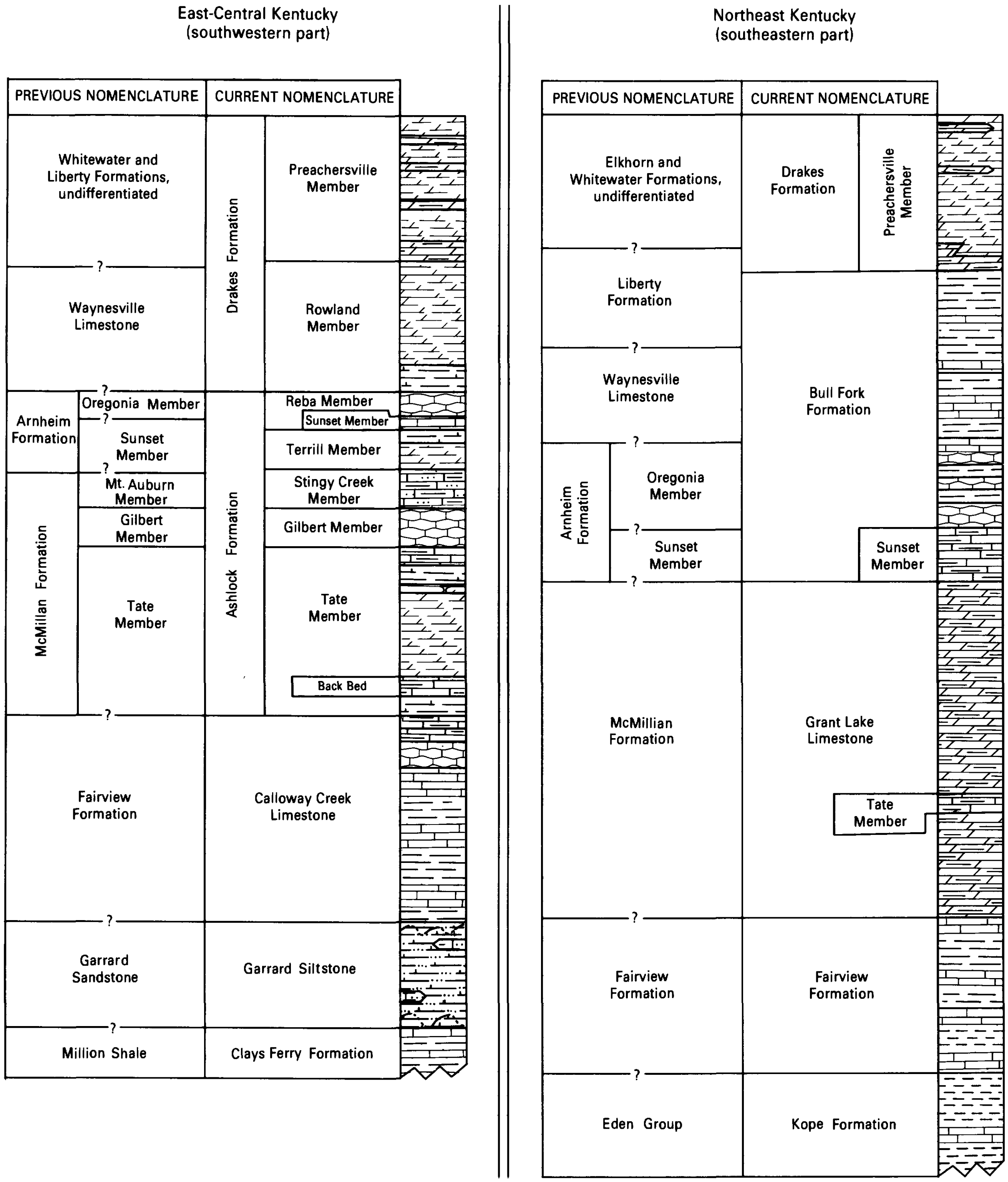

FIGURE 10.—Continued

TABLE 4.—*Abandoned and little-used stratigraphic names formerly applied in Kentucky to exposed strata of Ordovician age above the Lexington Limestone*

[Surnames generally follow usage of Palmquist and Hall (1961). Rank designation for some units varied according to author]

Name	Approximate stratigraphic position (as used in Kentucky)	Original reference	Kentucky usage	Recent discussion
Arnheim Formation	Bull Fork Formation, Ashlock Formation.	Foerste, 1905a, p. 150	Foerste, 1912a	Peck, 1966, p. B9-B10.
Bardstown Coral Reef in the Liberty Formation.	Drakes Formation	Foerste, 1903, p. 352	Browne, 1964, p. 389	Peterson, 1970, p. A38.
Blanchester Member of the Waynesville Formation.	Bull Fork Formation, Drakes Formation.	Foerste, 1909, p. 291	McFarlan, 1943, p. 31.	
Burkesville Limestone in the Cumberland Sandstone.	Cumberland Formation	Jillson, 1951a		
Clarksville Member of the Waynesville Formation.	Bull Fork Formation	Foerste, 1909, p. 292	McFarlan, 1943, p. 31.	
Corryville Shale Member of the McMillan Formation.	Grant Lake Limestone, Ashlock Formation.	Nickles, 1902, p. 83	McFarlan, 1943, p. 26	Peck, 1966, p. B8, B9.
Covington Group	Kope and Fairview Formations, Grant Lake Limestone, part of Bull Fork Formation.	Bassler, 1906, p. 9		
Cynthiana Formation	Lexington Limestone, Clays Ferry Formation.	Foerste, 1906, p. 10, 13	McFarlan and White, 1948, p. 1641-1643; Lattman, 1954.	Black, Cressman, and MacQuown, 1965, p. C2-C7.
Economy Member of the Latonia Shale.	Kope Formation	Bassler, 1906, p. 9	McFarlan, 1943, p. 23	Weiss and others, 1965, p. 27-28.
Elkhorn Formation	Bull Fork Formation, Drakes Formation.	Cumings, 1908, p. 678	Palmquist and Hall, 1960, sheet 3.	Utgaard and Perry, 1964, p. 17; Peck, 1966, p. B11-B12.
Fairmount Member of the Fairview Formation.	Fairview Formation, Calloway Creek Limestone.	Nickles, 1902, p. 78	Nosow and McFarlan, 1960, p. 44.	Ford, 1967, p. 928-931.
Fisherville Coral Reef in the Waynesville Formation.	Drakes Formation	Foerste, 1909, p. 291	Browne, 1964, p. 389	Kepferle, 1976b.
Fort Ancient Member of the Waynesville Formation.	Bull Fork Formation	Foerste, 1909, p. 292-293	McFarlan, 1943, p. 29.	
Fowler Limestone	Cumberland Formation	Foerste, 1901, p. 434		
Fulton Shale	Kope Formation, Clays Ferry Formation.	Foerste, 1905a, p. 150	McFarlan and Freeman, 1935.	Weiss and others, 1965, p. 27.
Haggard Limestone in the Cumberland Sandstone.	Cumberland Formation	Jillson, 1953		
Hudson River Group	Post-Lexington Limestone formations.	Mather, 1840, p. 212, 256-258.	Linney, 1882, p. 5-11	Wilmarth, 1938, p. 990.
Latonia Shale	Kope Formation	Fenneman, 1916, p. 63-65	Palmquist and Hall, 1961, pl. 1.	Weiss and others, 1965, p. 26; Luft, 1971b.
Laughery Formation	Bull Fork Formation	Foerste, 1912b, p. 22		
Liberty Formation	Bull Fork Formation; Drakes Formation.	Nickles, 1903, p. 207	Conkin, 1952, p. 126	Fox, 1962, p. 626.

TABLE 4.—*Abandoned and little-used stratigraphic names formerly applied in Kentucky to exposed strata of Ordovician age above the Lexington Limestone*—Continued

Name	Approximate stratigraphic position (as used in Kentucky)	Original reference	Kentucky usage	Recent discussion
Lorraine Group---------	Maysvillian Stage (Fairview Formation, Calloway Creek Limestone, Grant Lake Limestone, Ashlock Formation).	Emmons, 1842, p. 119-123---	Nickles, 1905, p. 29.	
McMicken Member of the Latonia Shale.	Kope Formation--------	Bassler, 1906, p. 10-------	McFarlan, 1943, p. 24---	Weiss and others, 1965, p. 27-28.
McMillan Formation-----	Grant Lake Limestone Ashlock Formation.	Bassler, 1906, p. 10-------	Nosow and McFarlan, 1960, p. 44.	Peck, 1966, p. B8-B9.
Million Shale----------	Clays Ferry Formation	Nickles, 1905, p. 25-26----	McFarlan, 1954----------	Weir and Greene, 1965, p. B3, B7.
Mount Auburn Member of the McMillan Formation.	Grant Lake Limestone, Ashlock Formation.	Nickles, 1902, p. 85-------	Nosow and McFarlan, 1960, p. 45.	Peck, 1966, p. B8-B9.
Mount Hope Shale Member of the Fairview Formation.	Fairview Formation, Garrard Siltstone.	Nickles, 1902, p. 76-------	McFarlan, 1943, p. 25---	Peck, 1966, p. B5, B7.
Oregonia Member of the Arnheim Formation.	Bull Fork Formation, Ashlock Formation.	Foerste, 1910, p. 18-------	Nosow and McFarlan, 1960, p. 46-47.	Peck, 1966, p. B9-B10.
Paint Lick Limestone---	Garrard Siltstone-----	Foerste, 1906, p. 212------	Nosow and McFarlan, 1960, p. 43.	Weir and others, 1965, p. D6.
Rennix Limestone-------	Cumberland Formation--	Foerste, 1901, p. 435		
River Quarry Beds------	Point Pleasant Tongue of the Clays Ferry Formation.	Orton, 1873, p. 370-378----	Nickles, 1902, p. 56-58.	Weiss and others, 1965, p. 18-19.
Rogers Gap Member of the Cynthiana Formation.	Clays Ferry Formtion, Kope Formation.	Foerste, 1912b, p. 23, 44--	McFarlan and Freeman, 1935.	Weiss and others, 1965, p. 19-20.
Southgate Member of the Latonia Shale.	Kope Formation--------	Bassler, 1906, p. 9--------	McFarlan, 1943, p. 23-24.	Weiss and others, 1965, p. 27-28.
Tanners Creek Formation.	Bull Fork Formation---	Fox, 1962, p. 626-628------	Hatfield, 1968, pl. 1---	Brown and Lineback, 1966, p. 1020.
Utica Formation--------	Kope Formation, Clays Ferry Formation.	Emmons, 1842, p. 116-118---	Foerste, 1906, p. 10----	Weiss and others, 1965, p. 26.
Versailles Formation---	Bull Fork Formation---	Foerste, 1905, p. 150		
Waynesville Formation--	Bull Fork Formation, Drakes Formation.	Nickles, 1903, p. 205-207--	McFarlan, 1943, p. 29, 31.	Peck, 1966, p. B10-B12.
Whitewater Formation---	Bull Fork Formation, Drakes Formation.	Nickles, 1903, p. 208-209--	Conkin, 1952------------	Peck, 1966, p. B2-B3; Brown and Lineback, 1966, p. 1022.
Winchester Limestone---	Clays Ferry Formation, Lexington Limestone.	Campbell, 1898, p. 2-------	Nickles, 1905, p. 15----	Weir and Greene, 1965, p. B2-B3, Black, 1974.

inch to about 4 in. and wavelengths of a few inches to a few feet. A few beds that contain coarse fossil fragments at the base, grading upward through medium to fine fragments, attest to reworking by currents.

Microscopically, the dominant limestone types in the Clays Ferry are biomicrosparrudite and biosparrudite. Biomicrosparite probably makes up as much as 10 percent of the limestone; biospararenite is less common. The biomicrosparrudite and biosparrudite are composed of a grain-supported framework of calcitic whole and broken fossils that commonly range from about 0.1 to 50 mm in maximum diameter. The framework-forming fossils are mostly brachiopods; less abundant are trilobites, echinoderms, and bryozoans; only locally abundant are gastropods and ostracodes. The framework of fossil fragments is cemented by anhedral microspar-forming crystals, generally 10 to 15 μm across and less commonly by sparry calcite-forming crystals, generally 30 to 100 μm across (fig. 11). Micrite is virtually absent. Sparry calcite occurs as: (1) recrystallizations of gastropod and brachiopod shells; (2) void fillings in gastropod shells, in bryozoan zooecia, and in geopetal structures floored by microspar; (3) syntaxial overgrowths on echinoderm ossicles; and (4) void fillings between fossil fragments.

A small amount of brown collophane fills bryozoan zooecia and minute gastropod shells. Pyrite occurs sparsely as silt-size grains, as replacements of fossils (particularly trilobite fragments), and, more rarely, as fillings of bryozoan zooecia. Unidentified opaque material that may be organic matter occurs as silt-size grains. Dolomite is mainly in irregular patches of silt-size rhombs and appears to replace microspar. Sparse angular quartz silt occurs mainly in the microspar.

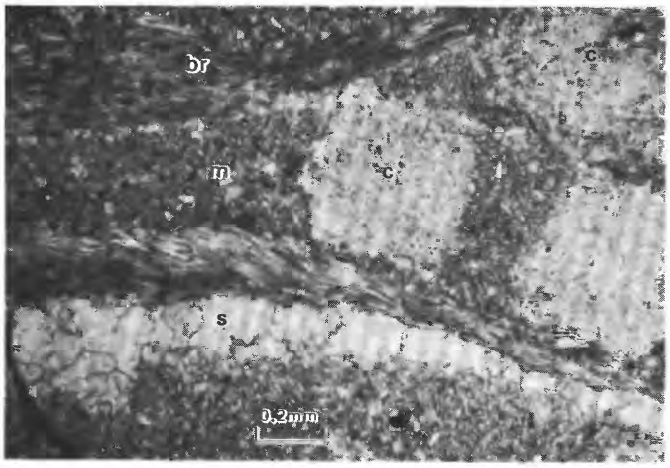

FIGURE 11.—Characteristic biomicrosparrudite from the Clays Ferry Formation, showing framework of crinoid (c) and brachiopod (br) fragments cemented by microspar (m) and lesser sparry calcite (s). Plane-polarized light.

The biomicrosparite is composed primarily of anhedral microspar grains, 20 to 40 μm in diameter, containing very sparse sand-size skeletal fragments. The biospararenite is composed mainly of fossil fragments and accessory silt-size grains of quartz and pyrite, all cemented by sparry calcite.

SHALE

Shale of the Clays Ferry Formation ranges from clayey to very silty, is mostly highly calcitic, and grades locally to limestone and siltstone. It is greenish gray or olive gray and weathers yellowish gray. Fossils, chiefly brachiopods, are relatively sparse. The shale is mostly in persistent sets, less than 6 in. thick, of obscure crude laminae. These sets tend to be thicker and reach a maximum thickness of several feet where shale is dominant. Thicker sets of shale are more characteristic of the Kope Formation with which the Clays Ferry locally intergrades. Some dominantly shale sequences, several tens of feet thick, within the Clays Ferry may be tongues of the Kope Formation. For example, a sequence about 60 ft thick, lying 40 ft below the top of the Clays Ferry in the Springfield, Mackville, and Cardwell quadrangles, central Kentucky, is as much as 90 percent shale; the sequence resembles tongues of the Kope but is not known to connect with the main body of the Kope.

Analyses by Scotford (1965, p. 205) of 41 samples, collected from localities fairly evenly distributed throughout the study area, of shale from a fossil-defined unit, the Fulton Shale as used by Passero (1961), now included in the Clays Ferry and Kope Formations, show that the dominant mineral is illite. Chlorite, mixed-layer chlorite, and mixed-layer illite are other clay minerals present in significant amounts. The mean shale mineralogy (in weight percent) of these samples was: illite (51.1), quartz (17.3), chlorite (9.6), calcite (7.6), mixed-layer chlorite (4.6), mixed-layer illite (2.2), and a small but undetermined amount of dolomite and traces of kaolinite, feldspar, and pyrite. Analyses by Scotford (1965, p. 205) of samples of shale from the upper part of the Cincinnatian Provincial Series indicate that the mineralogy of shale in the younger units resembles that of the Clays Ferry and the Kope.

SILTSTONE

Siltstone in the Clays Ferry Formation is medium light gray to olive gray and weathers yellowish brown or, where highly calcitic, grayish orange. Most siltstone is calcitic, sparsely fossiliferous, and in persistent even beds, 1 to 6 in. thick. Siltstone also occurs locally in lenses, as much as 3 ft thick and several tens of feet long, that in places are contorted into ball-and-pillow structures. Siltstone beds are most abundant in the upper part of the Clays Ferry adjacent to the Garrard Siltstone.

SUBDIVISIONS

Mappable subdivisions of the Clays Ferry Formation are few and of relatively small extent (fig. 12). The most widely mapped horizon in the formation is the base of a zone of abundant *Sowerbyella*, a small butterfly-shaped brachiopod about 1.5 cm wide. This horizon is not at a constant position relative to the base or top of the formation (pl. 6). The base of the zone is at the base of the Clays Ferry in the Waddy quadrangle, northwestern central Kentucky; in much of central Kentucky, as at the type section, it is near the middle of the formation. Siltstone and crinoidal limestone are locally more common above the base of abundant *Sowerbyella*, but otherwise composition and bedding are about the same below as above the mapped horizon.

The Point Pleasant Tongue of the Clays Ferry Formation, a northward extension of the Clays Ferry, was

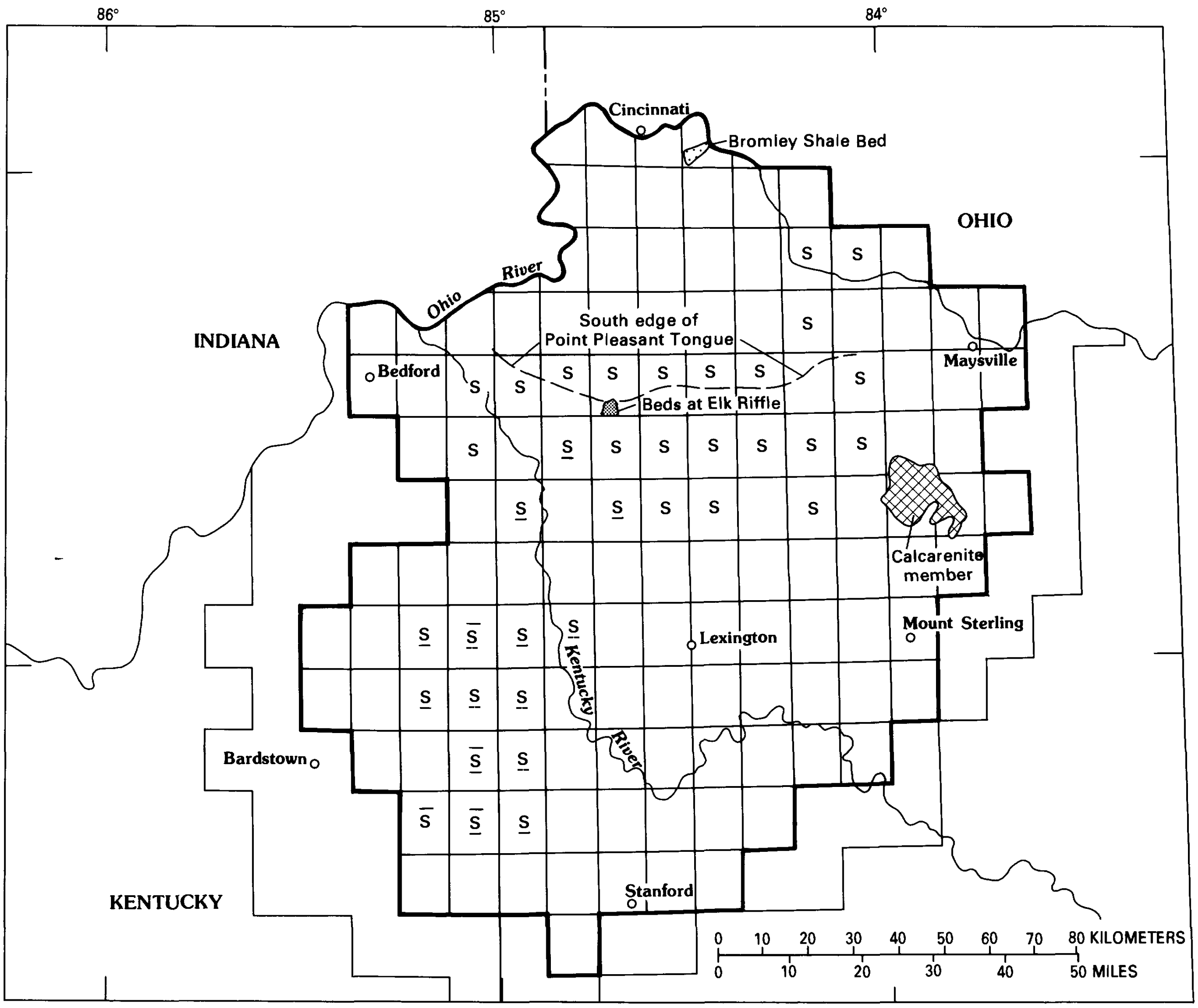

FIGURE 12.—Part of Kentucky, showing mappable subdivisions of the Clays Ferry Formation. Outcrop areas of the Bromley Shale Bed of the Point Pleasant Tongue, beds at Elk Riffle, and calcarenite member are generalized. S denotes quadrangles in which local exposures of base of zone of abundant *Sowerbyella* were marked by an x; S (underlined), where base of zone was mapped in part; S̄ (overlined), where top of zone was mapped in part. Heavy border outlines quadrangles containing outcrops of the Clays Ferry and Kope Formations.

named by Orton (1873, p. 370-378) for exposures at Point Pleasant, Ohio. The name has a complex history of usage (Weiss and others, 1965, p. 18-21). Swadley and others (1975) showed that the Point Pleasant is a stratiform body, lithologically like the Clays Ferry and geometrically related as a tongue to the main mass of the Clays Ferry, as in the Lawrenceville quadrangle, north-central Kentucky.

The Point Pleasant Tongue generally ranges from about 100 to 130 ft in thickness and extends throughout most of northern Kentucky. It overlies and in part intertongues with the Lexington Limestone and is overlain by the Kope Formation. The lower contact is distinct but exposed in only a few places, as in the Butler quadrangle, northeastern north-central Kentucky. The upper contact is placed in a generally gradational sequence so as to exclude thick sets of shale from the Point Pleasant.

In northern north-central Kentucky and the adjoining part of southwestern Ohio, the Point Pleasant includes the poorly exposed Bromley Shale Bed. This unit, named by Bassler (1906, p. 9) for outcrops formerly exposed near Bromley in the Covington quadrangle, consists of about 70 percent or more of gray sparsely fossiliferous slightly calcitic shale in sets 2 to 16 in. thick; gray fine- to medium-grained bioclastic limestone in thin to medium, even to irregular beds makes up the rest of the unit. The type area is now covered by the Ohio River, and the Bromley Shale Bed crops out only in a small area in the Covington and Newport quadrangles in Kentucky. The unit reaches a thickness of more than 80 ft in the subsurface near the Ohio River, but it thins abruptly southward by intertonguing with the dominantly limestone lithology of the Point Pleasant, and is only 11 ft thick at its southernmost point of recognition about 5 mi southwest of its type locality.

Unnamed tongues of the Clays Ferry Formation, similar to the Point Pleasant though generally much thinner, are intercalated with the Lexington Limestone and the Kope Formation at many localities. The Clays Ferry also contains a few unnamed intraformational members. Among these is a fine- to coarse-grained calcarenite member in the Sherburne and several adjoining quadrangles in southern northeastern and northern east-central Kentucky. The calcarenite, lying about 100 to 180 ft below the Fairview Formation, is dominantly coarse grained and composed of fairly well sorted subrounded fragments of brachiopods and bryozoans. The member is made up of trough sets, commonly 1 to 2 ft thick and 3 to 5 ft both wide and long, of low-angle crossbeds about 1 in. thick. The calcarenite is light olive gray and weathers very light gray. The member attains a maximum thickness of only 40 ft but forms conspicuous light-colored ledges of limestone in an area having few outcrops. Another minor but conspicuous unit within the Clays Ferry Formation has been mapped in the Lawrenceville quadrangle, north-central Kentucky. This unit, referred to as "beds at Elk Riffle" by Swadley (1975a), consists of irregularly bedded medium- to coarse-grained limestone, muddy micrograined limestone, and minor shale. The unit, which lies about 260 ft below the Fairview Formation and is as much as 20 ft thick, is resistant and forms good exposures along creek banks and in steep hollows.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Clays Ferry Formation crops out widely in the Blue Grass region of Kentucky, where it ranges from 0 to about 300 ft in thickness (fig. 13). It attains its maximum thickness in the Chaplin and Mount Eden quadrangles, northwestern central Kentucky.

Common stratigraphic relations of the Clays Ferry Formation are shown diagrammatically in plate 6. The Clays Ferry overlies and, over much of its extent, intertongues with the Lexington Limestone. In east-central and southern central Kentucky, it generally is conformably overlain by the Garrard Siltstone. In western central and most of north-central Kentucky, it is conformably overlain by the Calloway Creek Limestone. Locally, as in the Owenton quadrangle, north-central Kentucky, where the Clays Ferry intertongues and intergrades with the Kope, the overlying unit is the Fairview Formation. The Clays Ferry Formation complexly intertongues and intergrades with the Kope Formation in north-central, northeastern, and northern east-central Kentucky; locally it is overlain by a tongue of Kope, as in the Hedges quadrangle, east-central Kentucky. The Clays Ferry is not recognized in south-central Kentucky; it is probably equivalent to the unit described below as the Catheys(?) Formation.

CONTACTS

The Clays Ferry Formation, a relatively nonresistant unit, forms irregular steep slopes littered with platy fragments of limestone and calcitic siltstone, which locally cover the base of the formation. The contact with the underlying Lexington Limestone is commonly sharp and marked by a steepening of slope below. Where the formation intergrades or intertongues on a small scale with the Lexington Limestone, the contact is placed so as to include most shale and thin-bedded limestone in the Clays Ferry. The upper contact of the Clays Ferry commonly lies within a sequence characterized by intergrading rock types or small-scale intertonguing. Gradational sequences of the Clays Ferry and Kope Formations have been separated by placing the contact so as to exclude thick sets of shale from the Clays Ferry. The contact with the Garrard Siltstone has generally been mapped at the highest relatively persistent bed of limestone. Where the Clays Ferry Formation is overlain by the Calloway Creek Limestone or the Fairview Formation, the contact is generally indefinite in a poorly exposed gradational sequence; the contact is placed so as to include most shale in the Clays Ferry.

KOPE FORMATION

The Kope Formation was named by Weiss and Sweet (1964) for exposures of shale and minor limestone along Kope Hollow in the Russellville and Higginsport quadrangles, southwestern Ohio. Partial sections at Kope Hollow and Red Oak Creek, southwestern Ohio, and at Maysville, northeastern Kentucky, were designated cotypical sections.

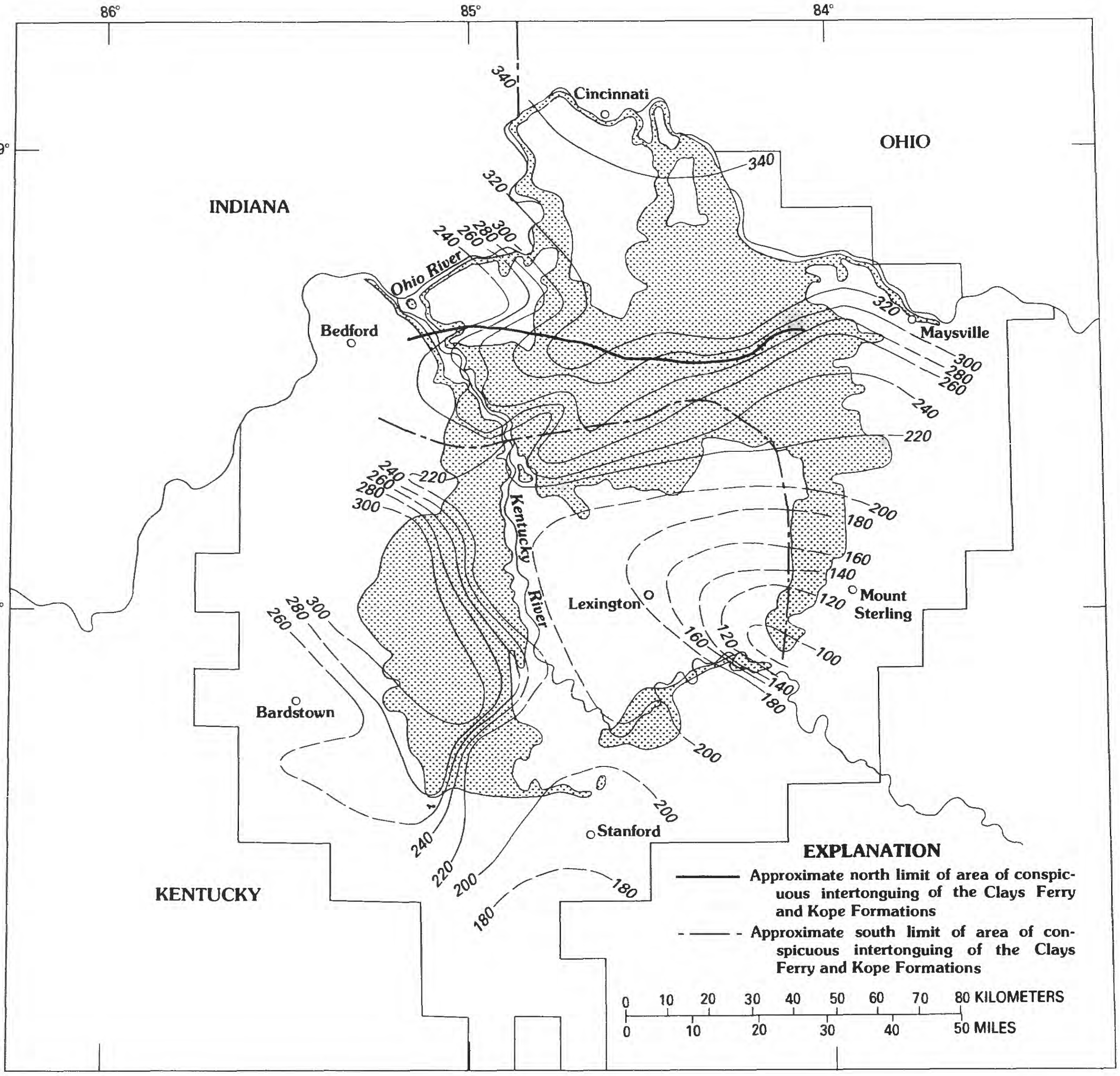

FIGURE 13.—Part of Kentucky, showing generalized area of outcrop (shaded) and thickness of the Clays Ferry and Kope Formations (combined). Contour interval, 20 ft; contours dashed where conjectural.

The Kope Formation is much like the partly equivalent Clays Ferry Formation, but the percentage of shale is larger, and the sets of shale thicker (fig. 14). The Kope consists of 60 to 80 percent shale and 20 to 40 percent limestone and, in places, minor siltstone. The shale, medium gray and greenish gray and weathering yellowish gray, is commonly calcitic and in part very silty. Detailed study by Bassarab and Huff (1969) of the clay mineralogy of shale in the upper part of the Kope exposed near Covington, Ky., and in Cincinnati, Ohio, showed a suite composed dominantly of illite (including some mixed illite-montmorillonite), chlorite, and vermiculite. The shale is mostly crudely to well laminated in sets 2 to 5 ft thick, which locally grade laterally into obscure irregular thin beds. Siltstone similar to that in the Clays Ferry locally intergrades with shale and limestone. Fossils are generally sparse in the shale and siltstone.

Limestone of the Kope is lithologically and petrologically similar to limestone of the Clays Ferry Formation. Booth and Osborne (1971), who studied clay minerals in insoluble residues from limestone of the Kope Formation near Cincinnati, Ohio, reported that illite makes up more than 75 percent of the total clay fraction and that chlorite and vermiculite form the remainder. Most of the limestone is in ledge-forming fairly continuous, even to irregular beds, 1 to 12 in. thick, that in places are grouped into sets a few feet thick. Limestone is also commonly interstratified in shale as single beds, a fraction of an inch to a few inches thick. Sets of limestone beds are generally thinner than in the Clays Ferry, but they become thicker and more numerous toward the south, where the Kope intertongues with the Clays Ferry.

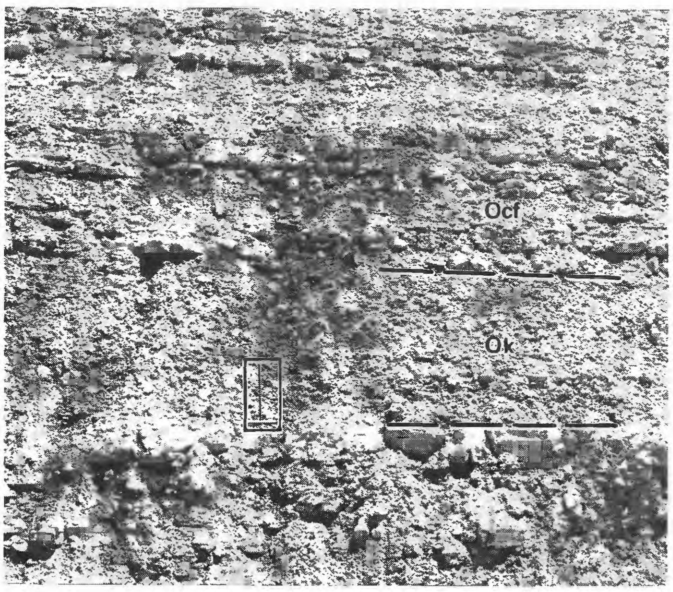

FIGURE 14.—Tongue of the Kope Formation (Ok) in the Clays Ferry Formation (Ocf). The Kope is about 80 percent shale and 20 percent thin-bedded limestone; the Clays Ferry is about 60 percent limestone and 40 percent shale. Horizontal rule (lower left) is 1 ft long; vertical rod is 2 ft long. Roadcut on Kentucky Highway 11 near Sherburne, Sherburne quadrangle, southern northeastern Kentucky.

Ripple marks occur on many limestone beds. Those in fine-grained limestone have amplitudes of less than an inch and wavelengths of less than a foot. Ripple marks in coarse-grained limestone are notably larger and commonly have amplitudes of 1 to 3 in. and wavelengths of 1 to 3 ft. Coarse-grained limestone also is locally crossbedded in trough sets a few inches thick. Hoffman (1966), who studied ripple marks and crossbeds in the Kope in the Ohio parts of the Addyston and Burlington quadrangles, observed that the orientation of these structures varies considerably but suggests a dominant transport direction to the west-northwest.

The Kope is a nonresistant formation, rarely exposed except in roadcuts and along streambanks. It forms moderate to steep slopes that in places are littered with slabs of limestone.

SUBDIVISIONS

Two subdivisions of the Kope Formation in the Cincinnati, Ohio, area were designated by Ford (1967, p. 925-928), but only one of these, the Grand Avenue Member, is recognized in Kentucky (Ford, 1968, p. 1780). The type section of this member is on an east-facing cliff just west of Grand Avenue (the source of the name) in central Cincinnati. The member consists of 11 ft of interbedded shale and limestone about 30 ft below the top of the Kope. It includes the same rock types as the main body of the formation but contains more limestone (about 40 percent). The higher limestone content of the member contrasts with the more shaly content of the underlying and overlying Kope and resembles the limestone content of sequences in the laterally equivalent Clays Ferry Formation and in the overlying Fairview Formation. Ford (1967, p. 925) suggested drawing contacts of the member so as to exclude sets of shale more than 2.5 ft thick. The Grand Avenue Member becomes unrecognizable a few tens of miles south of its type area, as in the Mason quadrangle, eastern north-central Kentucky, where the Kope intertongues with the Clays Ferry Formation. Ford (1967) also recognized the Wesselman Tongue of the Kope Formation, a unit of characteristic Kope lithology, which is intercalated with the Fairview Formation in northern Cincinnati; Ford's Wesselman thins and apparently pinches out southward before reaching Kentucky. Informal units of the Kope Formation include many unnamed tongues, commonly shown only in section, as in the Lawrenceville quadrangle, north-central Kentucky.

Thickness and Stratigraphic Relations

The Kope Formation crops out poorly over a wide area in north-central, northeastern, and northern east-central Kentucky (fig. 13). To the south it intergrades and intertongues with the Clays Ferry Formation in southern north-central and northern east-central Kentucky. Tongues of Kope are recognized as far south as the Hedges quadrangle, east-central Kentucky. From a maximum thickness of about 275 ft near Maysville, northeastern Kentucky, the formation thins gradually over a 60-mi distance westward to about 200 ft in the Patriot quadrangle, north-central Kentucky. The southward thinning is more rapid as the lower part of the Kope grades laterally into the Clays Ferry (pl. 6). Because the lateral relations of the Kope and Clays Ferry are complex and obscure, the two formations were mapped as a combined unit in many quadrangles.

In its type area and over most of its extent the Kope Formation overlies the Point Pleasant Tongue of the Clays Ferry Formation. Elsewhere, except for a few localities in north-central Kentucky where it rests on the Lexington Limestone, it overlies the Clays Ferry Formation. The Kope is overlain generally by the Fairview Formation or, in western central Kentucky, by the lateral equivalent of the Fairview, the Calloway Creek Limestone. In northeast east-central Kentucky the Kope is overlain by the Garrard Siltstone. Both the lower and upper contacts of the Kope range from sharp to obscure. In gradational sequences the contacts are drawn so as to include dominantly shale sequences and relatively thick sets of shale in the Kope Formation.

GARRARD SILTSTONE

The Garrard Siltstone was named by Campbell (1898, p. 2), who drew the name from Garrard County in east-central Kentucky but did not designate a type section. A representative section of the Garrard Siltstone below the type section of the Calloway Creek Limestone in the Ford quadrangle, eastern central Kentucky, was described by Weir and others (1965, p. D22) and diagrammed by Black and MacQuown (1965, p. 22). Campbell and most earlier workers designated the Garrard a sandstone; however, because most grains are in the silt size of Wentworth (1922), the formation name was modified to "Garrard Siltstone" by McFarlan (1954).

The Garrard is dominantly calcitic siltstone that in a few places grades to very silty limestone. The siltstone, greenish gray to light gray and weathering yellowish brown, is mostly in thin sets of laminae and very thin to medium, even beds, which are locally contorted into conspicuous ball-and-pillow structures (fig. 15). The Garrard generally contains only minor amounts of greenish-gray crudely laminated shale in partings and discontinuous seams, but in southern central Kentucky the formation contains as much as 20 percent shale. Light-gray fine- to coarse-grained limestone, mainly in irregular thin lenses and in patches mixed with siltstone, makes up less than 10 percent of the unit. Fossils are sparse except for brachiopods in some lenses of limestone. The formation crops out poorly and forms moderate slopes interrupted by a few ledges of contorted siltstone.

Microscopically, the Garrard Siltstone is composed dominantly of silt grains of quartz (30-40 percent) and minor feldspar, microcrystalline to finely crystalline anhedral calcite crystals, a green clay mineral, opaque grains, and sparse dolomite rhombs. The calcite mostly occurs as larger grains or clumps of grains within a groundmass of smaller grains of the other minerals. The long axes of all the grains tend to parallel the bedding. The quartz grains, locally cemented by overgrowths, seem to form a framework that encloses the calcite and other constituents. This framework and cementation may explain why some weathered outcrops of siltstone form resistant ledges and yield coherent blocks though completely leached of carbonate minerals.

Thickness and Stratigraphic Relations

The Garrard Siltstone extends throughout east-central Kentucky and into eastern central Kentucky, and ranges from 0 to about 100 ft in thickness. Thickness

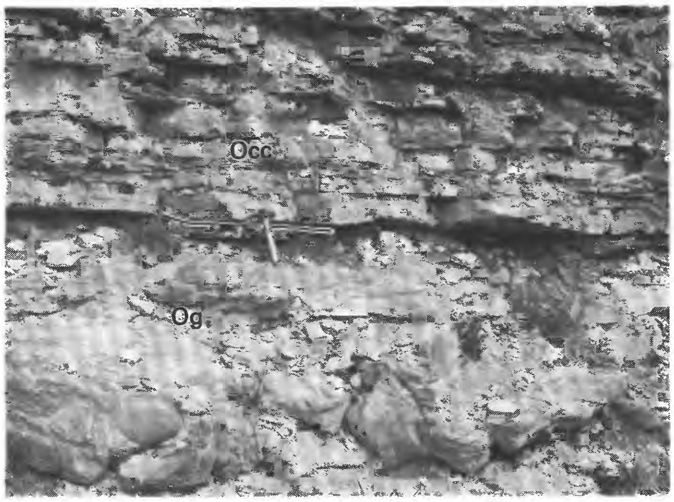

FIGURE 15.—Ball-and-pillow structures in the Garrard Siltstone. Contact between the Garrard Siltstone (Og) and the overlying Calloway Creek Limestone (Occ) is at pick. Rule (near center) is 1 ft long. Roadcut on Interstate Highway I-64, about 6 mi south of Mount Sterling, Sideview quadrangle, northern east-central Kentucky.

contours of the Garrard (fig. 16) involve much interpretation because the limits of the formation are commonly vague.

The Garrard Siltstone overlies the Clays Ferry Formation except in a few places, as in the Hedges quadrangle, east-central Kentucky, where it overlies the Kope Formation. The Garrard is overlain by the Calloway Creek Limestone except in northern east-central Kentucky, where it is overlain by the Fairview Formation. The Garrard intergrades and intertongues with both the overlying and underlying formations. The zones of transition, in which siltstone, shale, and limestone are interlayered, range in thickness from a few feet to several tens of feet. The contacts of the formation as considered in this report are placed so as to exclude from the Garrard persistent beds of limestone. Some workers (Greene, 1966a; Black, 1968) placed the contacts so as to include in the Garrard all relatively thick beds of siltstone. In many places, however, such inclusion would result in a much greater thickness than that shown on the map (fig. 16).

The Garrard Siltstone feathers out into a poorly exposed zone of limestone, shale, and siltstone in the upper part of the Clays Ferry Formation in southwestern central and northern east-central Kentucky. The Garrard is not recognized as a separate unit north or west of the Gravel Switch quadrangle, central Kentucky, or north of the Owingsville quadrangle, east-central Kentucky. In southern central Kentucky, the Garrard includes much shale in the middle part of the formation. Thick units of siltstone at the top and base of the Garrard in the Hustonville quadrangle apparently pinch out southward within about 10 mi because no Garrard was recognized in cores from drill holes in the northeast part of the Dunnville quadrangle, northern south-central Kentucky.

FAIRVIEW FORMATION

The name "Fairview," drawn from Fairview Heights in Cincinnati, Ohio, was given by Bassler (1906, p. 10) to a unit of closely interbedded limestone and shale whose boundaries were faunally defined. The Fairview was later redefined by Ford (1967, p. 928-931) in terms of the lithology of a type section exposed along Clifton Avenue in Cincinnati.

The Fairview Formation is characterized by evenly bedded limestone interlayered with approximately equal amounts of shale and minor siltstone. The general aspect of the formation resembles, in part, the Clays Ferry Formation and differs from the laterally adjoining Calloway Creek Limestone primarily in bedding style and limestone content. At its type section, the Fairview is made up of about 40 percent limestone and 60 percent

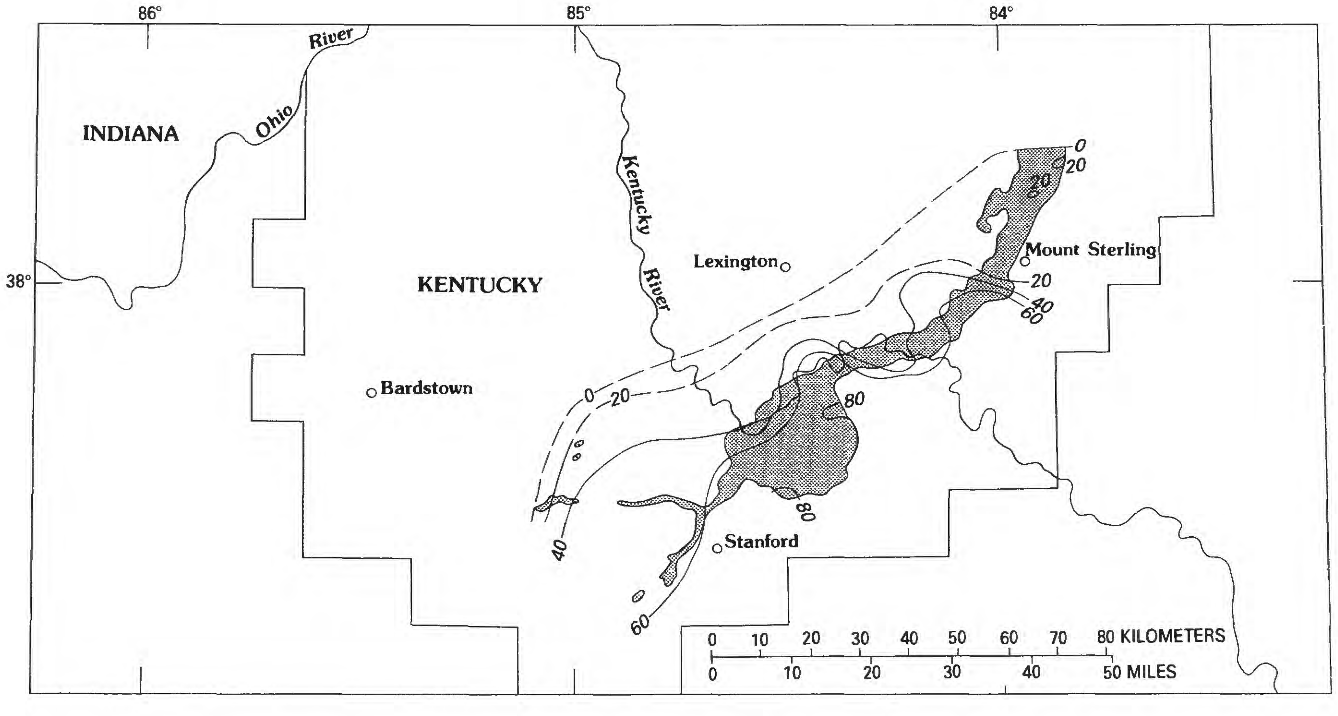

FIGURE 16.—Part of Kentucky, showing generalized area of outcrop (shaded) and thickness of the Garrard Siltstone. Contour interval, 20 ft; contours dashed where conjectural.

shale and siltstone. The limestone content increases southward to about 55 percent in the Walton quadrangle, northern north-central Kentucky, and to as much as 70 percent at the south edge of the formation, as in the Sharpsburg quadrangle, northern east-central Kentucky.

Limestone of the Fairview, mostly medium gray to olive gray and weathering light gray or yellowish gray where silty, is chiefly of two types. The more abundant type is limestone consisting of whole fossils and fine to very coarse fragments of fossils in a micrograined to medium-grained matrix. Brachiopods and bryozoans are quantitatively the most significant rock-forming fossils; trilobites, crinoids, gastropods, cephalopods, and ostracodes are locally important. The fossil-fragmental limestone is in fairly persistent, even to slightly irregular beds that average about 4 in. in thickness. Large ripple marks, having amplitudes of about 1 to 4 in. and wavelengths of about 1 to 4 ft, occur locally. Some layers of coarse-grained limestone are crossbedded in thin sets. Hoffman (1966), who studied ripple marks and crossbeds in the Fairview in the Ohio parts of the Addyston and Burlington quadrangles, observed that these structures show a wide range of orientations, which on the average suggest a dominant southerly paleocurrent direction.

The less abundant type of limestone in the Fairview is micrograined to fine grained, in part clayey to silty, and contains sparse fossil fragments. It is in continuous even beds, generally 1 to 6 in. thick, commonly sheathed with laminae of very calcitic siltstone. A few silty micrograined limestone beds have been contorted into ball-and-pillow structures, as much as 1 ft thick.

Microscopically, the common limestone types of the Fairview are generally similar to those of the Clays Ferry Formation and Calloway Creek Limestone. Booth and Osborne (1971), who studied clay minerals of insoluble residues from limestone of the Fairview Formation near Cincinnati, Ohio, reported that illite makes up more than 75 percent of the total clay fraction, and chlorite and vermiculite the remainder.

Shale, which makes up 25 to 60 percent of the Fairview, is mostly calcitic and silty, medium gray to greenish gray, and weathers grayish yellow. It is in sets, a fraction of an inch to about 1 ft thick, of obscure to distinct, irregular and even laminae. The shale is irregularly fissile and generally contains few fossils.

Siltstone, which makes up as much as 15 percent of the Fairview, is calcitic, sparsely fossiliferous, and locally grades to silty micrograined limestone. The siltstone is medium gray, weathers yellowish brown, and is stratified in laminae and very thin beds grouped in sets as much as 6 in. thick.

The Fairview, one of the more resistant formations in the Upper Ordovician of Kentucky, forms moderate to steep slopes studded with ledges and littered with slabs of limestone. Good exposures are common along streambanks and in steep hollows. Relatively thick layers of brachiopodal limestone, at the base of the Fairview in many areas, form prominent ledges.

Thickness and Stratigraphic Relations

The Fairview Formation crops out in southwestern Ohio and in northeast and northern north-central Kentucky. Over much of northern Kentucky the Fairview is more than 100 ft thick (fig. 17). At the type section in Cincinnati, Ohio, it is 108 ft thick. It thickens southward to a maximum of about 130 ft in the Alexandria quadrangle, north-central Kentucky, then thins irregularly to the southwest and southeast. The minimum thickness reported is 40 ft in the Sherburne quadrangle, northeast Kentucky.

The Fairview generally overlies the Kope Formation. Near its south limit, the Fairview overlies a unit of intertongued beds of the Clays Ferry and Kope Formations; in northern east-central Kentucky, it overlies the thin northward extension of the Garrard Siltstone. The contact is placed in a gradational sequence, 5 to 20 ft thick, so as to separate interbedded limestone and shale above from dominantly shale strata below. In northern northeast Kentucky, as in the Maysville East quadrangle, the base of the Fairview is a prominent ledge, 2 to 6 ft thick, of brachiopodal limestone containing abundant valves of *Strophomena*. In northern north-central Kentucky, as in the Verona quadrangle, a similar ledge-forming set of limestone beds containing abundant small dalmanellid brachiopods marks the contact. Near the south limit of the Fairview in northeast Kentucky, the contact is placed in a gradational sequence at the base of the lowermost persistent limestone bed above relatively thick and persistent beds of siltstone.

At the top of the Fairview Formation in parts of the Addyston, Burlington, and Covington quadrangles, northern north-central Kentucky, is an unmapped unit, as much as 10 ft thick, composed of shale containing a few thin beds of fine-grained muddy limestone. This unit is the Miamitown Shale, in this report classified as a member of the Fairview Formation. Ford (1967, p. 931-932) defined the Miamitown as a formation in Ohio and designated as the type section roadcuts on Interstate Highway I-74, 1 mi west of Miamitown (for which the unit is named) and about 12 mi northwest of Cincinnati. The Miamitown Shale Member of the Fairview Formation is as much as 35 ft thick in Ohio 4 mi northwest of Miamitown. The Miamitown lithologically resembles the Kope Formation and may be a southeasterly thinning tongue of the Kope or of the somewhat more limy Dillsboro Formation.

The Fairview grades by a marked increase in shale content northwestward into the Dillsboro and, possibly, also into the Kope Formation in Indiana. The Fairview grades laterally southward into the Calloway Creek Limestone (pl. 7) with an increase in limestone content, an increase in the abundance of fossils (particularly brachiopods and bryozoans), and a change in bedding style to the more irregular thinner limestone beds and shale partings characteristic of the Calloway Creek. The cutoff marking the change is placed in the Carrollton quadrangle, western north-central Kentucky, and thence along a poorly defined line that runs southeasterly through the Sharpsburg quadrangle, northern east-central Kentucky.

The Fairview Formation is everywhere overlain by the Grant Lake Limestone. The contact is placed in a transitional zone, commonly about 5 to 20 ft thick, so as to generally exclude dominantly nodular-bedded lime-

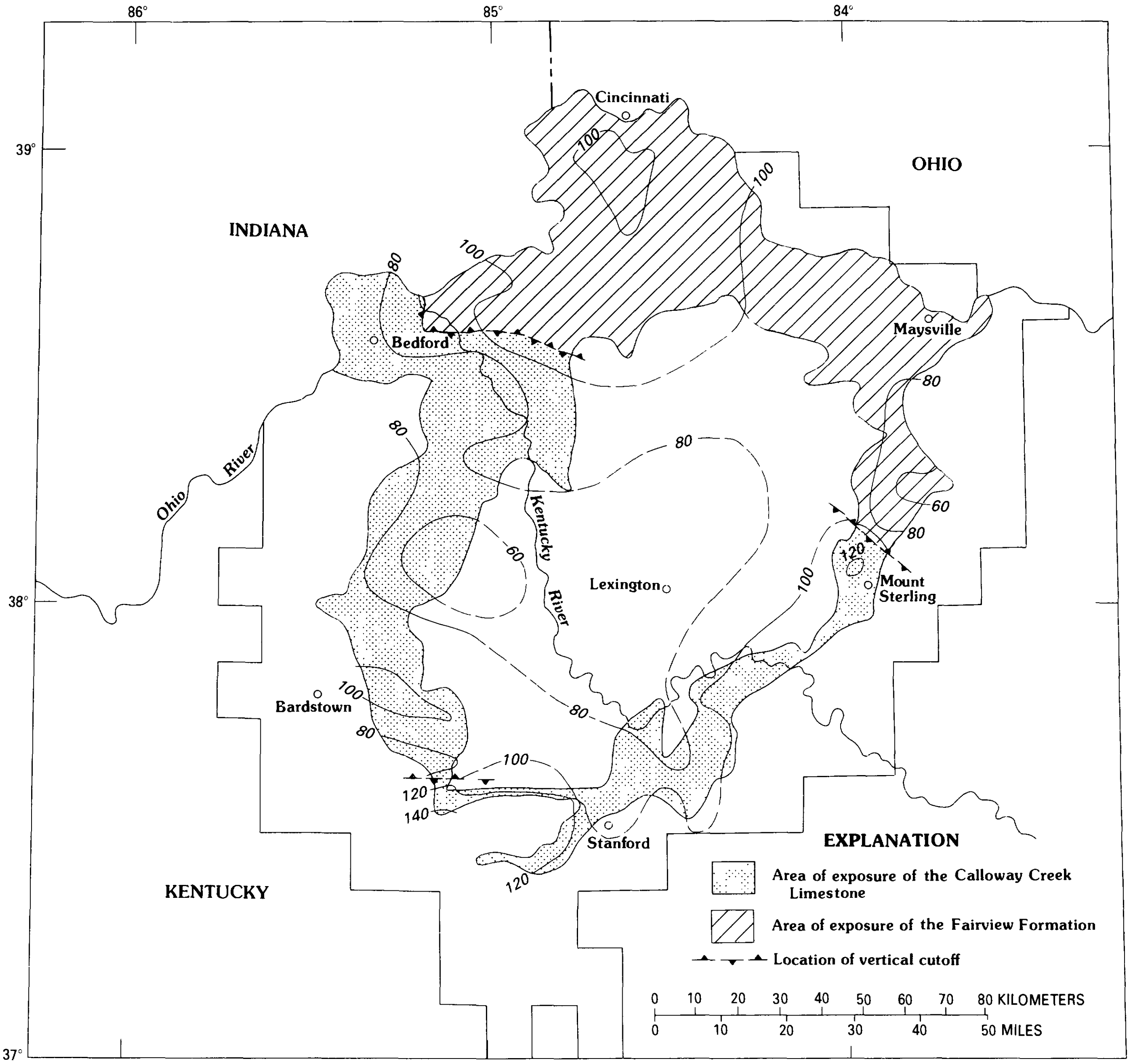

FIGURE 17.—Part of Kentucky, showing generalized area of outcrop and thickness of the Fairview Formation and the Calloway Creek Limestone. Contour interval, 20 ft; contours dashed where conjectural.

stone from the Fairview. In western north-central Kentucky, the contact is characterized by a ledge-forming set of crossbedded calcarenite at the base of the Grant Lake Limestone.

CALLOWAY CREEK LIMESTONE

The Calloway Creek Limestone was described by Weir and others (1965, p. D6-D9, D20-D21) from roadcuts along Interstate Highway I-75 near Calloway Creek in the Richmond North quadrangle, east-central Kentucky (sec. EC-14, pl. 3).

The Calloway Creek Limestone is composed dominantly of medium-gray fossiliferous limestone and lesser amounts of shale and siltstone. The limestone, which generally makes up more than 70 percent of the formation, is of two main types. Dominant is shelly limestone consisting mostly of abundant fine to coarse fragments and some whole skeletons of brachiopods and bryozoans in a very fine grained to medium-grained calcite matrix. The shelly limestone is in rough-surfaced, even and uneven thin beds, commonly less than 6 in. thick. The relatively thicker beds are fairly continuous; thinner beds are lensing. In east-central Kentucky, much of the upper part of the Calloway Creek is nodular bedded (fig. 18). In western central and north-central Kentucky, sparsely fossiliferous micrograined to fine-grained limestone in even thin beds is conspicuous near the top of the formation.

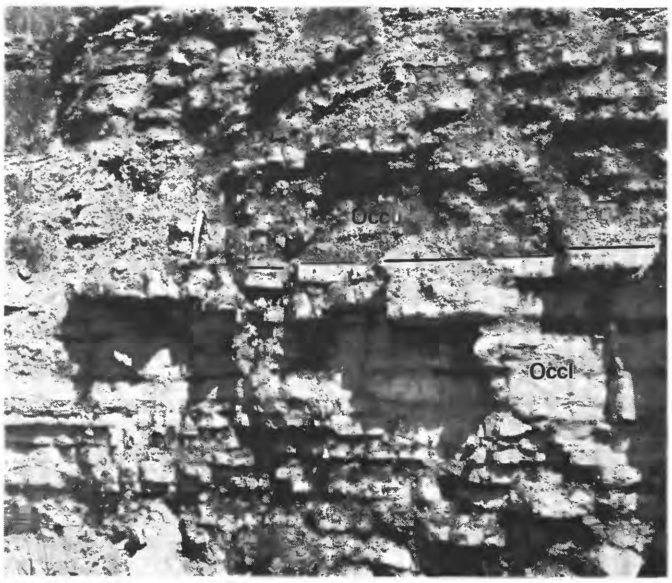

FIGURE 18.—Calloway Creek Limestone, in roadcut on Interstate Highway I-64 about 3 mi northeast of Mount Sterling, Mount Sterling quadrangle, northern east-central Kentucky. Upper part of Calloway Creek (Occu) above pick head is mostly nodular bedded; lower part of Calloway Creek (Occl) is in irregular planar beds.

Microscopic examination shows that most of the limestone in the Calloway Creek is biosparrudite, consisting of a grain-supported framework of whole and broken calcitic fossils, which range from about 0.1 to 30 mm across, cemented by sparry calcite. Sparse brown collophane fills bryozoan zooecia. Dolomite occurs in scattered rhombs and in irregular patches of subhedral crystals. Sparse pyrite and quartz occur as silt-size grains. Less common but present in significant amounts is limestone made up of loosely packed brachiopod valves or fragments of branching bryozoans set in a mixture of finely crystalline anhedral calcite, finely crystalline euhedral dolomite, and silt-size grains of quartz and pyrite.

Greenish-gray and gray shale and calcitic shale are interstratified as partings and thin sets fairly evenly through most of the Calloway Creek Limestone. In the lower 10 to 30 ft, the sets of shale are generally thicker and the proportion of shale greater. Gray siltstone is in continuous even beds, a few inches thick, and is mostly in the lower third of the formation.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Calloway Creek Limestone extends around the west, south, and east sides of the Blue Grass region of Kentucky. It ranges from about 60 to 140 ft in thickness (fig. 17); abrupt changes in thickness are due to vertical cutoffs.

The Calloway Creek Limestone, whose complex stratigraphic relations are shown in plate 7, has limits that in many places are arbitrary because it grades into adjoining formations. The Calloway Creek Limestone is separated by cutoff from the intergrading and intertonguing Fairview Formation in eastern north-central Kentucky, as in the Carrollton quadrangle. In northern east-central Kentucky, as in the Sharpsburg quadrangle, the planar-bedded lower part of the Calloway Creek (fig. 18) is separated by cutoff from similar rock in the lower member of the Grant Lake Limestone (sec. *B-B'*, pl. 7). In southwestern central Kentucky, the formation intergrades with the lower part of the Grant Lake Limestone and is separated from the lower Grant Lake by a cutoff at the latitude of the north edge of the Lebanon West quadrangle (fig. 17). The Calloway Creek Limestone passes in the subsurface southward into the Leipers Limestone of south-central Kentucky; the cutoff is placed south of the southernmost outcrops of the Calloway Creek, at the latitude of the south edge of the Hustonville quadrangle.

The Calloway Creek Limestone conformably overlies the Garrard Siltstone in east-central and southeastern central Kentucky. The contact is placed at the base of the lowermost persistent bed of limestone, thus generally excluding siltstone beds more than 6 in. thick (fig. 15). In most of central and southern north-central Kentucky, it conformably overlies the Clays Ferry Formation. Near its north cutoff in north-central Kentucky, as in the Carrollton quadrangle, the Calloway Creek Limestone overlies the Kope Formation or, as in the Owenton quadrangle, a unit of intertongued beds of the Kope and Clays Ferry. The zone of transition with the Clays Ferry or Kope crops out poorly and ranges from about 5 to 30 ft in thickness. The contact is placed in the middle or upper part of the transition zone so as to exclude from the Calloway Creek thick sets of shale and beds of micrograined limestone more characteristic of the underlying formation.

The Calloway Creek Limestone is overlain by calcitic and dolomitic mudstone of the Tate Member of the Ashlock Formation in east-central and southern central Kentucky. The zone of lithologic transition ranges from a few inches to a few feet in thickness. The contact is placed so as to include most beds of fossiliferous limestone in the Calloway Creek. In north-central and most of central Kentucky, where the Calloway Creek is overlain by the Grant Lake Limestone, the contact is placed at the base of a conspicuous thin but persistent set of beds and crossbeds of calcarenite so as to exclude from the Calloway Creek most beds of calcarenite and nodular beds, which are more characteristic of the Grant Lake (fig. 19).

FIGURE 19.—Contact between the Calloway Creek Limestone (Occ) and the Grant Lake Limestone (Ogl) characteristic of western central and north-central Kentucky. Ledge-forming unit (c) above contact is calcarenite, previously included on some geologic maps as part of the Calloway Creek. Shovel is 3.5 ft long. Roadcut on Kentucky Highway 148, Simpsonville quadrangle, northwestern central Kentucky.

GRANT LAKE LIMESTONE

The Grant Lake Limestone was defined by Peck (1966, p. B14-B16, B23-B24) on the basis of roadcut exposures along Kentucky Highway 1449 in the Maysville East and Orangeburg quadrangles, northeastern northeast Kentucky. The name is drawn from that of a small lake about 2.5 mi southwest of the type section.

The Grant Lake is composed of limestone (70-90 percent) interbedded and intermixed with shale. The limestone, mainly light to medium gray and weathering lighter gray or yellowish gray, mostly consists of abundant whole to finely broken fossils in a muddy poorly sorted micrograined to medium-grained calcite matrix. The formation is characterized by irregularly continuous to lensing, nodular thin beds consisting of limestone lenticles, commonly 3 to 4 in. long and 1 to 2 in. thick, separated by curving laminae of shale.

Microscopically, most limestone of the Grant Lake is biosparrudite or biomicrudite. Fossil fragments, commonly ranging from about 0.1 to 30 mm across, form a grain-supported fabric cemented by sparry calcite or, less commonly, by micrite. The large fossil fragments are mostly of brachiopods, branching bryozoans, and trilobites. Fragments less than 2 mm in diameter also commonly include crinoid plates, ostracodes, and gastropods. Oncolites, 1 to 2 cm in diameter, composed of a skeletal fragment enveloped in concentric layers of micrite, are generally uncommon, but they are a conspicuous lithologic element in beds near the top of the Grant Lake in the Owingsville and adjoining quadrangles in northern east-central Kentucky (fig. 20) and also in beds about 20 ft above the base of the formation in the Campbellsburg and adjoining quadrangles in western north-central Kentucky.

Sparry calcite chiefly occurs as interstitial filling of the fossil-fragmental framework but also occurs commonly as recrystallizations of gastropod shells and, to a lesser degree, of brachiopod shells. The calcite forms geopetal fills beneath single brachiopod valves, and fillings of gastropod shells and bryozoan zooecia. Some irregular areas of spar may be fillings of shrinkage cracks in the micritic groundmass.

Pyrite is common as angular silt-size grains, as irregular fillings between calcite crystals, as replacements of trilobite fragments, and as fillings of bryozoan zooecia. Brown collophane is sparse as fillings of bryozoan zooecia and ostracode shells. Chert is present as replacements of fossil fragments. Quartz silt is rare. Clay minerals were not identified, but they are present in an undetermined amount in patches of cloudy matrix.

Interlayered irregularly with the nodular-bedded limestone is planar-bedded fossil-fragmental limestone, similar to the limestone characteristic of the Fairview Formation. This planar-bedded limestone, interstratified with some shale, is generally only a minor constituent of the Grant Lake, but locally in northeast Kentucky, as in the Mays Lick quadrangle, it makes up as much as a third of the formation.

Coarse-grained limestone (calcarenite locally grading to calcirudite) locally makes up as much as 10 percent of the Grant Lake in the Owingsville and adjacent quadrangles, northern east-central Kentucky, and in the Bedford and adjacent quadrangles, western north-central Kentucky. The calcarenite is similar in composition to the more common type of limestone but contains more large whole brachiopods and large skeletal fragments cemented by coarse to very coarse spar. Although poorly sorted, the calcarenite generally lacks the muddy streaks and patches found in most limestone of the Grant Lake. The calcarenite is in irregular planar and nodular beds, as much as 1 ft thick, and in trough sets, as much as 3 ft thick, of low-angle thin crossbeds. The calcarenite is lighter gray and more resistant than other limestone in the Grant Lake and so generally forms conspicuous ledges.

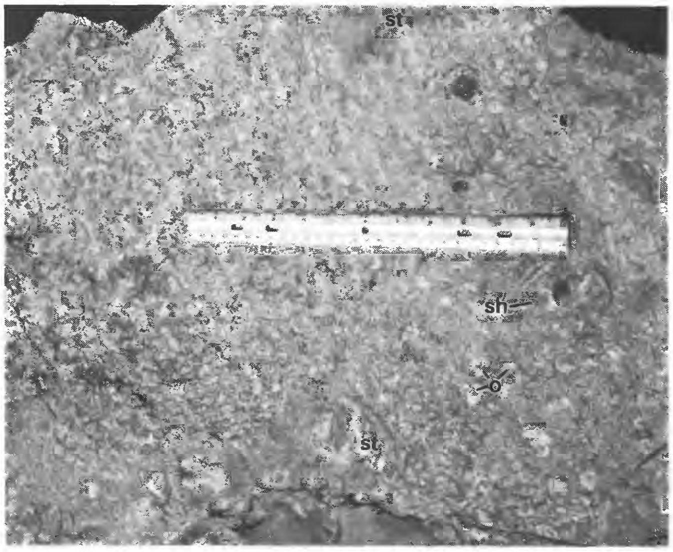

FIGURE 20.—Weathered upper surface of bed of oncolitic limestone near top of the Grant Lake Limestone. Oncolites (o) are light-gray roundish blotches; stromatolite fragments (st) are faintly laminated darker gray patches; sparse shell fragments (sh) of brachiopods are also present. Outcrop near U.S. Highway 60 about 2 mi west of Owingsville, northern east-central Kentucky.

Shale of the Grant Lake Limestone is medium gray to greenish gray, calcitic, and in part silty. It forms irregular partings and thin interbeds around lenticles of limestone and also is obscurely mixed with limestone in vague, irregular thin beds. Microscopic study shows that some shale contains abundant dolomite rhombs and silt-size pyrite grains in a clayey micritic groundmass.

The Grant Lake Limestone is made up dominantly of whole and fragmented fossils. Large thick-shelled brachiopods, especially *Platystrophia ponderosa* and *Hebertella*, and branching and massive bryozoans are the most conspicuous rock-forming faunal elements. Gastropods, cephalopods, pelecypods, crinoids, trilobites, and encrusting algae are locally significant lithologic elements.

The Grant Lake Limestone as a whole is a relatively nonresistant unit and commonly forms gentle to moderate slopes interrupted by a few ledges of more resistant limestone. Most outcrops weather readily to yield a rubble of nodular fragments and coarse fossil debris. Where the formation includes thick sets of calcarenite, as in northern east-central and western north-central Kentucky, it crops out well along streambanks and in steep hollows, and gives rise to moderately steep slopes with prominent thick ledges.

THICKNESS AND STRATIGRAPHIC RELATIONS

The limits of the Grant Lake Limestone assigned in this report differ in minor ways from those on some geologic-quadrangle maps. The mapped boundaries of the Grant Lake and other formal units generally match boundaries of lithofacies, but owing primarily to differences in exposure, the grouping of lithofacies into formations and members differs locally. The earlier usage of the name "Grant Lake" and other formal names with respect to the chief lithofacies was summarized in a diagram (similar to pl. 7) by Weir, Peterson, and Swadley (1979a). The thin Terrill and Reba Members of the Ashlock Formation were mapped as an undifferentiated top part of the Grant Lake Limestone in southern central Kentucky, south and east of Bardstown. A persistent calcarenite unit, a few feet thick, mapped as the basal unit of the Grant Lake in northwestern north-central Kentucky, was mapped as the top unit of the Calloway Creek Limestone in southwestern north-central Kentucky. In this report, the calcarenite unit is placed at the base of the Grant Lake (fig. 19). In the Fisherville and Simpsonville quadrangles, western north-central Kentucky, is a sequence, several tens of feet thick, that is lithologically like the Bull Fork Formation but, because too few exposures were present for comparison, was included in the Grant Lake; this sequence is included in the Bull Fork on plate 7. These minor changes better adjust the stratigraphic names to the lithofacies characteristic of the formations.

The Grant Lake Limestone is exposed in two arcuate areas on the east and west sides of the Blue Grass region (fig. 21). On the east it is 109 ft thick at its type section and thickens southward to 140 ft in the Elizaville quadrangle, northeast Kentucky. South of this quadrangle the Grant Lake thins, in part by intergrading with members of the Ashlock Formation and the upper part of the Calloway Creek Limestone. The Grant Lake is considered a member of the Ashlock from the Mount Sterling quadrangle, east-central Kentucky, southward;

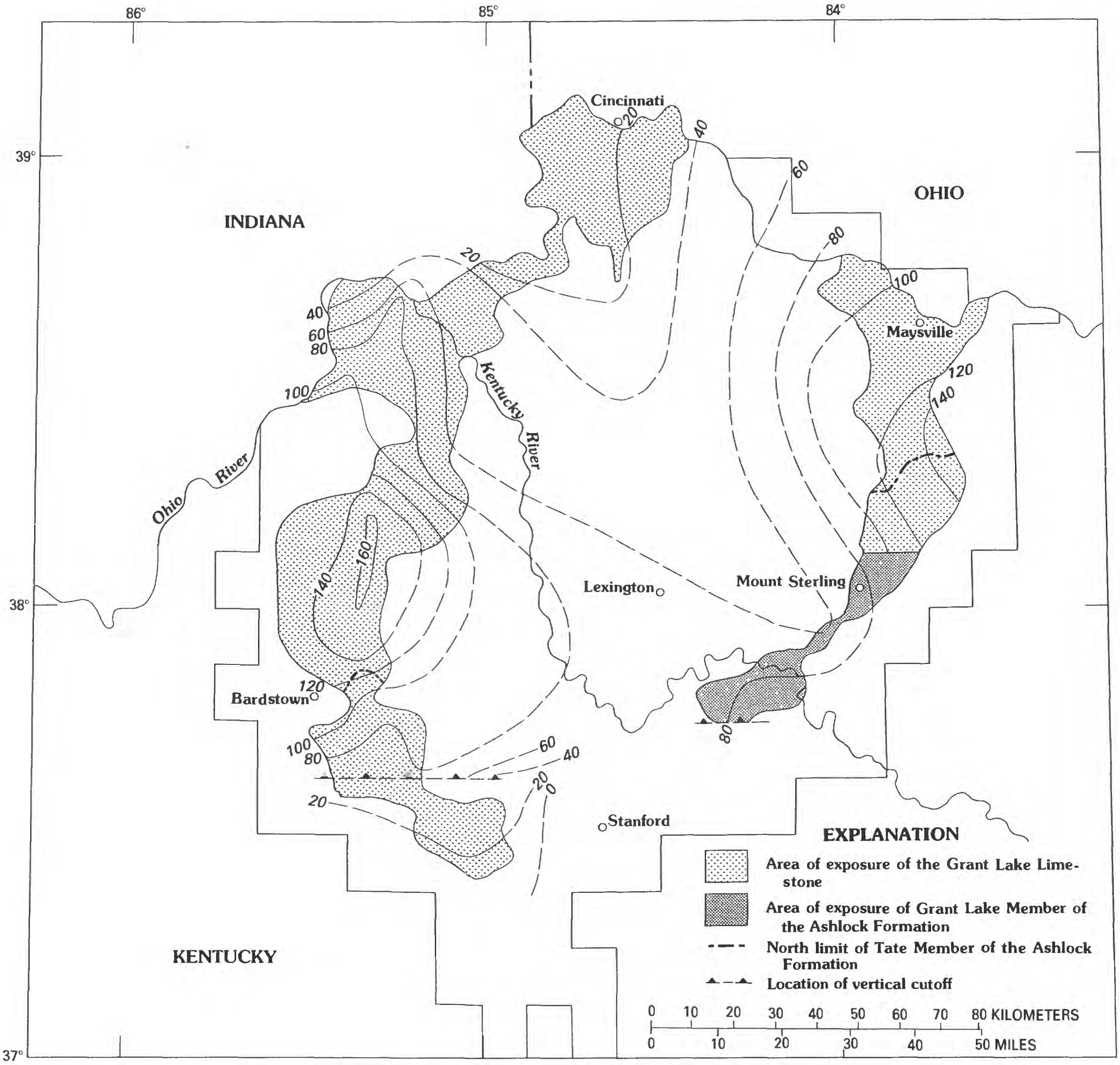

FIGURE 21.—Part of Kentucky, showing generalized area of outcrop and thickness of the Grant Lake Limestone and the Grant Lake Member of the Ashlock Formation. Contour interval, 20 ft; contours dashed where conjectural. Abrupt changes in thickness result from vertical cutoffs at south edge of upper part of the Grant Lake Limestone in southwestern central Kentucky and at south edge of the Grant Lake Member of the Ashlock Formation in southwestern east-central Kentucky.

it terminates by cutoff from the Stingy Creek and Gilbert Members and the upper part of the Tate Member at the latitude of the south edge of the Richmond North quadrangle, east-central Kentucky. On the west the Grant Lake Limestone reaches its maximum thickness of about 160 ft in the Taylorsville and Simpsonville quadrangles, northwestern central Kentucky, whence it thins irregularly northward until it is only 3 ft thick locally in the Patriot quadrangle, northern north-central Kentucky. The formation also thins southward from the Taylorsville quadrangle and shows abrupt changes in thickness where it is separated by cutoff from intergrading parts of the Calloway Creek Limestone and the Ashlock Formation in southwestern and southern central Kentucky.

The thin northern wedge of the Grant Lake Limestone in the Union and adjacent quadrangles, in northern north-central Kentucky, is designated the Bellevue Tongue of the Grant Lake Limestone (Swadley, 1969a). In the eastern belt of outcrop, as in the Sherburne and several adjoining quadrangles, the Grant Lake Limestone includes as a member the thin northeastward extension of the Tate, which is discussed in this report in connection with the Ashlock Formation.

The Grant Lake Limestone has been divided into informal upper and lower members in the northeastern and southwestern parts of the Blue Grass belt of outcrop. In northeastern northeast Kentucky, as in the Orangeburg and several adjacent quadrangles, an upper member is differentiated lithologically by the presence of a noticeable amount of planar-bedded limestone. In northern east-central Kentucky, these upper and lower members are lithologically alike but are separated by the thin Tate Member (cross sec. *B-B′*, pl. 7); the lower member is separated from the upper part of the Calloway Creek Limestone by a cutoff at the north boundary of the Mount Sterling quadrangle. In southwestern and southern central Kentucky, the Grant Lake Limestone is split into upper and lower members by a wedge consisting of the Tate and Gilbert Members of the Ashlock Formation (cross sec. *C-C′*, pl. 7). The lower member of the Grant Lake in southern Kentucky is separated by cutoff from the upper part of the Calloway Creek Limestone at the latitude of the north edge of the Lebanon West quadrangle. The upper member is separated from the Terrill and Reba Members of the Ashlock Formation by cutoff near the latitude of Bardstown in southwestern central Kentucky, and from the Stingy Creek Member of the Ashlock by a cutoff at the longitude of the west edge of the Junction City quadrangle.

In its type area and across northern Kentucky, the Grant Lake overlies the Fairview Formation. The contact is placed in a transition zone, commonly 5 to 20 ft thick, so as to separate dominantly nodular bedded limestone and shale above from planar-bedded limestone and shale below. In the western belt of outcrop the contact with the Calloway Creek is locally indefinite, but it is sharp in much of western north-central and central Kentucky where a persistent unit of crossbedded calcarenite lies at the base of the Grant Lake Limestone.

Where the Grant Lake is ranked as a member of the Ashlock Formation, from the Mount Sterling quadrangle to the Richmond North quadrangle in east-central Kentucky, the Grant Lake lies between units composed dominantly of dolomitic to calcitic mudstone. It overlies the Tate Member of the Ashlock and is overlain by the Terrill Member of the Ashlock. The contacts with these members are generally sharp, but locally the Grant Lake is obscurely transitional with the underlying Tate Member through a zone as much as 5 ft thick.

ASHLOCK FORMATION

The Ashlock Formation was named by Weir and others (1965, p. D9-D16, D23-D27) for exposures near Ashlock Cemetery in the Lancaster quadrangle, southern east-central Kentucky. The type section was described from outcrops along the Dix River and from roadcuts along U.S. Highway 27, chiefly in the Lancaster quadrangle (sec. EC-2, pl. 3).

The Ashlock consists of alternating units of limestone and calcitic to dolomitic mudstone, which locally intertongue, intergrade, and pinch out. The rocks are mostly light gray, olive gray, and greenish gray, and weather light gray or yellowish gray. The limestone is mostly in thin to medium, continuous and discontinuous, even to nodular beds. The mudstone is in obscure to well-defined laminae and thin beds.

The term "Ashlock Formation" denotes a convenient assemblage of lithologically distinct units that facilitate mapping at 1:24,000 scale in east-central Kentucky. In southern east-central Kentucky, the Ashlock Formation consists, in ascending order, of the Tate, Gilbert, Stingy Creek, Terrill, and Reba Members. In northern east-central Kentucky, it consists of the Tate, Grant Lake, Terrill, Sunset, and Reba Members. In southern central Kentucky, the Ashlock consists of only the Tate and Gilbert Members. The rock types of the Tate and Terrill Members are continuous with similar rock types in the Cumberland Formation of south-central Kentucky; thus, the Tate and Terrill could be viewed as northern tongues of the Cumberland. In much the same way, the rock types and bedding characteristic of the Stingy Creek and Reba Members are continuous with similar rocks in the Grant Lake Limestone in the northern part of the State; these members could be considered tongues of the Grant Lake Limestone. These lithologic affinities are shown in part in plate 7 and are discussed further in the section entitled "Lithofacies."

The Ashlock Formation crops out around the south and east borders of the Blue Grass region of Kentucky. It ranges from about 60 to 150 ft in thickness. Most of the abrupt changes in thickness are related to vertical cutoffs between intergrading formations.

For most of its extent the Ashlock Formation conformably overlies the Calloway Creek Limestone and is conformably overlain by the Drakes Formation (pl. 7). In a few localities in southeastern central Kentucky, as in the Stanford quadrangle, it is unconformably overlain by rocks of Devonian age. In southwestern central Kentucky, in the Maud and Bardstown quadrangles, the Ashlock intertongues and intergrades with the Grant Lake Limestone and is separated from the Grant Lake by a cutoff near the latitude of Bardstown. In northern east-central Kentucky, the Ashlock intergrades with the Grant Lake Limestone and the lower part of the Bull Fork Formation, and is separated from these formations by a vertical cutoff at the latitude of the north edge of the Mount Sterling quadrangle. In south-central Kentucky, the Ashlock grades into the Cumberland Formation and is separated from the Cumberland by a cutoff at the latitude of the south edge of the Yosemite quadrangle.

TATE MEMBER

The Tate was named by Foerste (1906, p. 212), apparently for exposures near Tate Creek in the Richmond North quadrangle, east-central Kentucky. Although no type section was designated, the unit is well exposed not far from Tate Creek along Interstate Highway I-75 about 6 mi north of Richmond, Ky. A representative section of the Tate Member at the type section of the Ashlock Formation (sec. EC-2, pl. 3) was described by Weir and others (1965, p. D25-D27).

The Tate Member is dominantly micrograined to fine-grained muddy limestone and muddy calcitic dolomite. Streaks and small patches of a light-green clay mineral are sparsely distributed throughout the muddier rocks. In southern east-central Kentucky, the Tate grades mostly to dolomitic and calcitic mudstone. In southwestern central Kentucky, it includes a few thin lenses of medium- to coarse-grained limestone. Figure 5 plots the mineralogic composition of the Tate Member, calculated from chemical analyses of representative samples of mudstone and muddy limestone. The mudstone of the Tate is more calcitic than similar mudstone higher in the section. Stratification is commonly obscure but consists mostly of even laminae and thin beds. Mud cracks, low-amplitude ripple marks, and trace fossils occur sparsely on bedding planes. Most rocks in the Tate are shades of greenish gray and weather yellowish gray, pale olive, and, less commonly, grayish orange. Fossils are generally rare; branching and globular bryozoans are common in some beds of limestone, especially near gradational boundaries of the member. The Tate is relatively nonresistant and forms a gentle slope that commonly steepens slightly near the top.

Microscopic study shows that the Tate Member is generally composed of sparse to abundant micrograined and very fine grained fossil fragments, commonly unidentifiable, and of euhedral dolomite, anhedral calcite, interstitial micrite, angular quartz, an unidentified green clay mineral, pyrite, opaque material, and clots of sparry calcite (fig. 22). Particles other than micrite are mostly larger than 10 and less than 100 μm across. Percentages of the constituents vary, but commonly minute fossil fragments are dominant, and dolomite is second in abundance. Identifiable fossil fragments are mostly of ostracodes but also include fragments of gastropods, echinoderms, trilobites, bryozoans, and brachiopods. The sparry calcite occurs as partially recrystallized shell material and apparently also as fillings in shrinkage cracks and burrow openings.

Near the base of the Tate in east-central Kentucky is a persistent thin unit of light- to olive-gray limestone (secs. EC-2, EC-8, EC-14, pl. 3; cross sec. *B-B'*, pl. 7). This unit is the Back Bed of the Tate Member, named for Back Creek in the Paint Lick quadrangle, east-central Kentucky (Weir and others, 1965, p. D10-D11). The limestone is poorly sorted, fine to medium grained, in

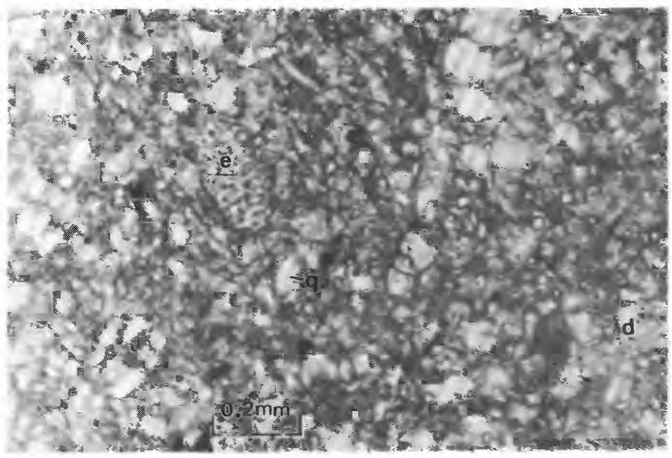

FIGURE 22.—Muddy limestone of the Tate Member of the Ashlock Formation. Dominant light-gray grains are mostly minute fragments of skeletal material, including echinoderms (e); darker gray material is mostly green clay mineral. Also shown are a few quartz (q) and opaque grains, and euhedral crystals of dolomite (d). Plane-polarized light.

part muddy, and is mostly in thin nodular to planar, nodular-surfaced beds that contain many fossils, chiefly large brachiopods and bryozoans. The Back Bed ranges from about 3 to 10 ft in thickness and forms a minor ledge about 5 to 15 ft above the base of the member (fig. 23). Where that part of the Tate Member below the Back Bed grades to nodular-bedded limestone, the Back Bed is not separable from the underlying formation. Thus, on the north the Back Bed and the basal part of the Tate merge with the Grant Lake Limestone in the Sharpsburg quadrangle, on the south with the Calloway Creek Limestone in the Stanford quadrangle.

The Tate Member crops out around the south and southeast sides of the Blue Grass region of Kentucky and ranges from 0 to about 80 ft in thickness (fig. 24). The Tate Member is a persistent unit throughout east-central Kentucky. Near Richmond, however, the upper part of the member grades northeasterly from dominantly calcitic and dolomitic mudstone into fine- to medium-grained muddylimestone and is separated from similar rock in the Grant Lake Member of the Ashlock Formation by cutoff at the north edge of the Richmond South quadrangle. The Tate thins and grades to micrograined limestone north of the Mount Sterling quadrangle, northern east-central Kentucky, and pinches out in the Grant Lake Limestone in the Sherburne quadrangle, southern northeast Kentucky. The Tate is present across southern central Kentucky but interfingers and grades out northward into the Grant Lake Limestone in the Maud and Bardstown quadrangles, southwestern central Kentucky.

Foerste (1912, p. 23) assigned the Tate Member to the now-abandoned McMillan Formation. It is presently considered the basal member of the Ashlock Formation (Weir and others, 1965, p. D10-D11) except north of Mount Sterling, Ky., where it is classed as a member of the enclosing Grant Lake Limestone (Outerbridge, 1970).

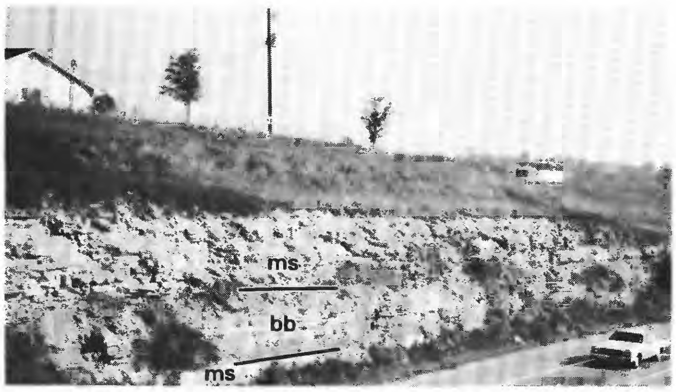

FIGURE 23.—Back Bed (bb) of the Tate Member of the Ashlock Formation. Mudstone (ms) characteristic of the Tate is exposed above and below nodular-bedded limestone of the Back Bed. The Back Bed is about 8 ft thick at this locality. Roadcut on Interstate Highway I-64 about 2 mi northeast of Mount Sterling, Mount Sterling quadrangle, northern east-central Kentucky.

In most of east-central and southeastern central Kentucky, the Tate rests on the Calloway Creek Limestone; elsewhere it rests on the lower member of the Grant Lake Limestone (pl. 7). In southern east-central and southern central Kentucky, the Tate is overlain by the Gilbert Member of the Ashlock Formation; elsewhere it is overlain by the Grant Lake. Contacts range from sharp to obscure. The lithology of the Tate is transitional through a few inches to as much as 5 ft with the underlying and overlying fossiliferous limestone. The contact has been mapped at the top or near the middle of the zone of transition so as to exclude most nodular-bedded fossiliferous limestone from the Tate.

GILBERT MEMBER

The Gilbert Member (of the now-abandoned McMillan Formation) was named by Foerste (1912b, p. 18, 23), probably for outcrops near the town of Gilbert in the Lancaster quadrangle, southeastern east-central Kentucky. Weir and others (1965, p. D12, D25) described a type section from roadcuts along U.S. Highway 27 about 1 mi west of Gilbert and assigned the member to the Ashlock Formation (sec. EC-2, pl. 3).

The Gilbert is dominantly micrograined limestone interstratified with lesser amounts of fine- to medium-grained limestone and calcitic silty shale. The limestone is bluish to olive gray; the silty shale is medium to dark gray. The darker shades characteristic of the member contrast with the lighter shades of the overlying and underlying units. Irregularly spheroidal masses, commonly 1 to 3 in. in diameter, of coarse crystals of yellowish-white calcite occur sporadically in the limestone throughout the member. The limestone is in continuous, even, nodular-surfaced to nodular beds, commonly a few inches thick, interstratified with partings and seams of crudely laminated silty shale. Fossils range in abundance from sparse to common in the member, but because they do not weather out from the micrograined matrix, they are generally inconspicuous. The dominant fossils differ from place to place but are mostly ostracodes, brachiopods (including the large *Platystrophia ponderosa*), small branching bryozoans, low-spired gastropods, orthoconic cephalopods, fragmented trilobites, and grayish-brown stromatoporoids. The member, which is relatively resistant and crops out more extensively than other members of the Ashlock, commonly forms a ledgy, steep slope.

Microscopically, most limestone of the Gilbert is biomicrite, composed of micrite in which are scattered whole and fragmented fossils ranging from about 0.1 to 30 mm across. The fossil material generally makes up less than 20 percent of the rock and does not form a grain-supported framework. Algal-coated grains (oncolites) are locally common. Abundant sparry calcite occurs mostly as fillings of cavities of fossils and as recrystallized shell material; aggregates of dolomite crystals are rare.

Less common in the Gilbert is biosparite, consisting of sand-size grains cemented by sparry calcite. The biosparite contains scattered whole and coarsely broken fossils that make up only a few percent of the rock. The grains tend to be rounded and are composed mostly of crinoid plates and fragments of brachiopods, bryozoans, and trilobites. Algal-coated grains are also present. Dolomite rhombs are common in the groundmass. Pyrite is rare. Chert replaces some brachiopod shells. Sparse collophane fills zooecia of bryozoans and replaces some fossil fragments.

The Gilbert Member of the Ashlock Formation crops out around the south margin of the Blue Grass region of Kentucky (fig. 25) and ranges in thickness from a few feet to about 20 ft. Near Richmond, east-central Kentucky, the Gilbert becomes coarser grained and muddier and is separated from similar but muddier limestone of the Grant Lake Member of the Ashlock by

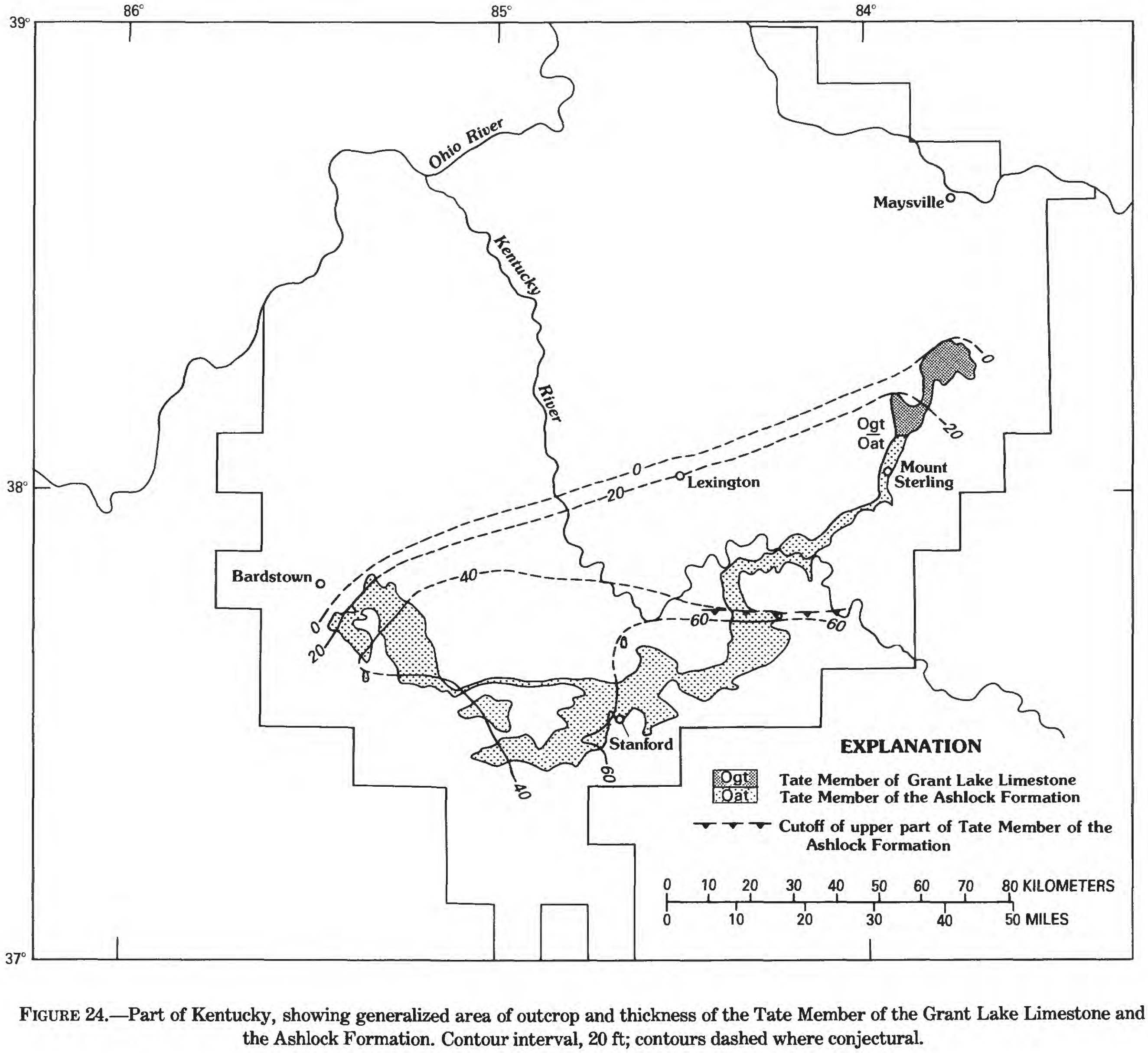

FIGURE 24.—Part of Kentucky, showing generalized area of outcrop and thickness of the Tate Member of the Grant Lake Limestone and the Ashlock Formation. Contour interval, 20 ft; contours dashed where conjectural.

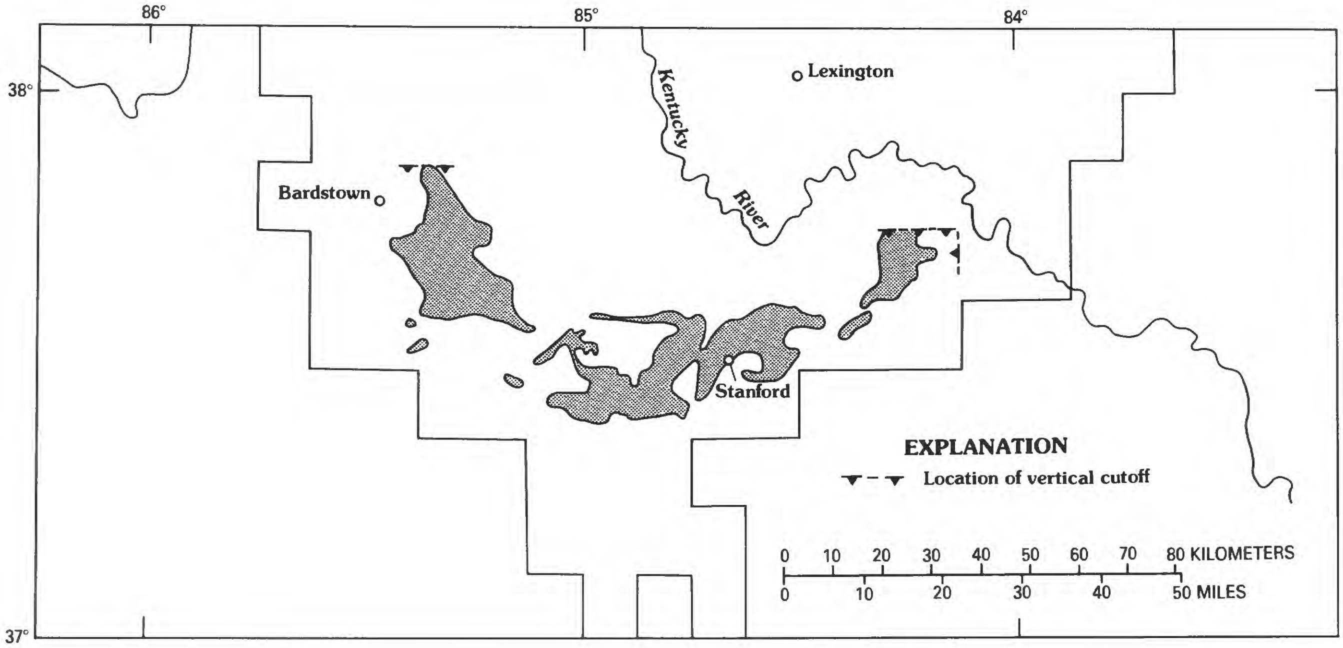

FIGURE 25.—Part of Kentucky, showing generalized area of outcrop (shaded) of the Gilbert Member of the Ashlock Formation.

cutoffs at the north edge of the Richmond South and Moberly quadrangles and the east edge of the Moberly quadrangle. Similarly, in southwestern central Kentucky, the Gilbert grades into the Grant Lake Limestone in the northern parts of the Bardstown and Maud quadrangles. Southward from the type area the Gilbert Member apparently becomes more dolomitic and merges with the Cumberland Formation in northern south-central Kentucky. Fossiliferous dolomitic limestone at the probable stratigraphic level of the Gilbert is locally conspicuous in outcrops of the Cumberland in the Dunnville quadrangle and is probably continuous in the subsurface with the Gilbert Member of the Ashlock exposed in the Yosemite quadrangle.

The Gilbert rests on the Tate Member of the Ashlock Formation except near its gradeout in the Maud quadrangle where it rests on the lower part of the Grant Lake Limestone (pl. 7). The Gilbert is overlain in east-central Kentucky by the Stingy Creek Member of the Ashlock, and in most of central Kentucky by the Stingy Creek or its correlative, the upper part of the Grant Lake Limestone (fig. 26). Locally, as in the western part of the Hustonville quadrangle, the Stingy Creek is missing, and the overlying unit is the Terrill Member of the Ashlock Formation.

The Gilbert is generally a conspicuous unit, relatively easy to separate from overlying and underlying units, even though contacts in detail may be obscure. In east-central Kentucky, the zone of intergradation with

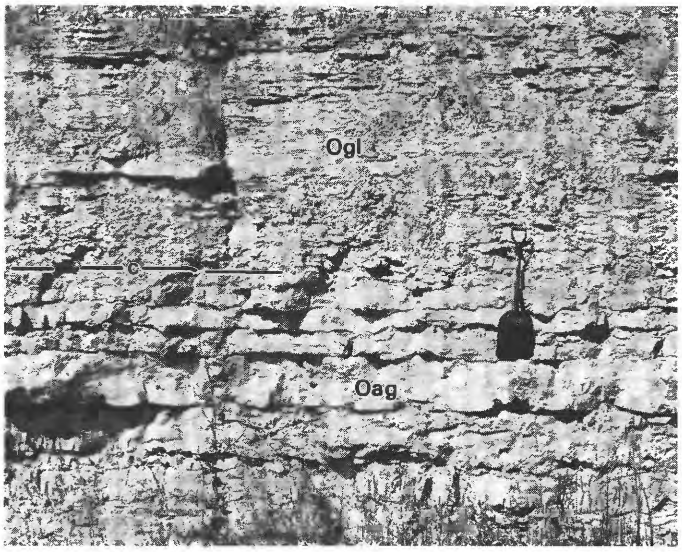

FIGURE 26.—Contact (c) between the Gilbert Member of the Ashlock Formation (Oag) and the Grant Lake Limestone (Ogl). The Gilbert is chiefly micrograined limestone. The Grant Lake is nodular-bedded limestone and shale. Shovel is 3.5 ft long. Roadcut on U.S. Highway 150 about 1 mi northwest of Fredericktown, Maud quadrangle, western central Kentucky.

the Tate Member is commonly less than a foot thick; in southern central Kentucky, it is commonly several feet thick. The contact is placed within the zone of intergradation so as to include most nodular-bedded fossiliferous limestone in the Gilbert. Locally, as at the type section of the Ashlock Formation, the basal contact may be confused by the presence of a thin set of limestone beds resembling the Gilbert within the Tate about 11 ft below the top of the Tate. The zone of intergradation with the overlying Stingy Creek or Grant Lake is commonly a few feet thick. The upper contact is placed within the zone of transition so as to exclude from the Gilbert most nodular-bedded fine- to medium-grained muddy limestone.

Stingy Creek Member

The Stingy Creek Member of the Ashlock Formation was named by Weir and others (1965, p. D13, D25) for characteristic outcrops along Stingy Creek in the southern part of the Lancaster quadrangle, east-central Kentucky. The type section was described from roadcuts on U.S. Highway 27 in the western part of the Lancaster quadrangle (sec. EC-2, pl. 3).

The Stingy Creek is composed of medium-gray and olive-gray fine- to medium-grained silty limestone, intermixed, intergrading, and interbedded with a nearly equal amount of calcitic silty shale. The limestone is in thin discontinuous nodular beds interlayered with thin irregularly wavy sets of crudely laminated shale. Fossils are abundant, chiefly abraded brachiopods (including the large *Platystrophia ponderosa*) and branching bryozoans. The member crops out poorly and generally forms a fossil-strewn gentle slope. The Stingy Creek Member resembles the Reba and Grant Lake Members, but the Stingy Creek contains more shale and is in thinner, more discontinuous beds.

The Stingy Creek overlies the Gilbert Member and is overlain by the Terrill Member of the Ashlock Formation. The zone of intergradation with the Gilbert is a few feet thick; the contact is placed so as to include in the Stingy Creek Member most discontinuous nodular beds of fine- and medium-grained limestone. The upper contact is fairly sharp; the zone of intergradation is commonly only a few inches thick.

The Stingy Creek Member is restricted to the southeast margin of the Blue Grass region (fig. 27), where it ranges from 0 to about 15 ft in thickness. Southwest of its type section the member thins and pinches out in the southwestern part of the Hustonville quadrangle, southeastern central Kentucky. West of its type section the Stingy Creek becomes less silty and contains more continuous beds and is separated arbitrarily from similar rock in the upper part of the Grant Lake Limestone by a cutoff at the east edge of the Parksville quadrangle. Northeast of its type section it grades similarly into the Grant Lake Member of the Ashlock Formation; the cutoff is at the north borders of the Richmond North and Moberly quadrangles.

Terrill Member

The Terrill Member of the Ashlock Formation was named by Weir and others (1965, p. D13, D29) for exposures near the town of Terrill in the Richmond South quadrangle, east-central Kentucky. The type section was described from roadcuts along Kentucky Highway 52 in the Moberly quadrangle, east-central Kentucky (sec. EC-10, pl. 3).

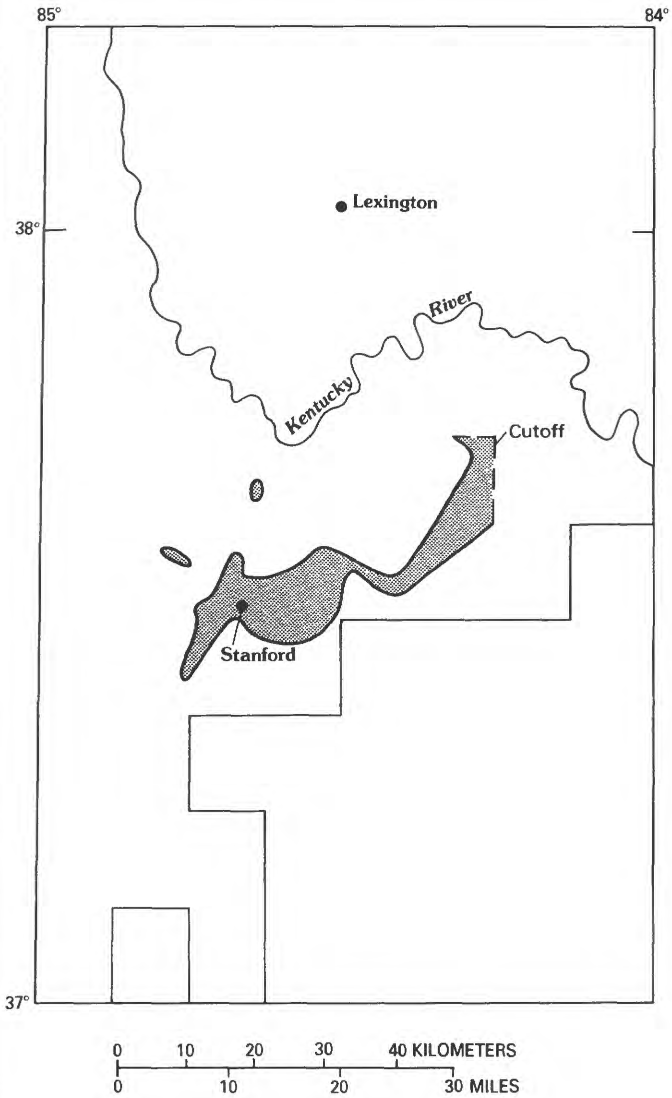

FIGURE 27.—Part of Kentucky, showing generalized area of outcrop (shaded) of the Stingy Creek Member of the Ashlock Formation.

The Terrill Member is composed mainly of light-greenish-gray calcitic to dolomitic mudstone (fig. 28); greenish-gray muddy dolomite to dolomitic limestone makes up a small part of the member. Figure 5 plots the calculated mineralogic composition of representative samples of the Terrill Member. The member weathers a fairly uniform grayish yellow to yellowish gray, is laminated to very thin bedded, and contains sparse mud cracks, ripple marks, and trace fossils. Megafossils are absent except locally near gradational boundaries. The Terrill is relatively nonresistant and commonly forms a minor recess or gentle slope that steepens toward the top.

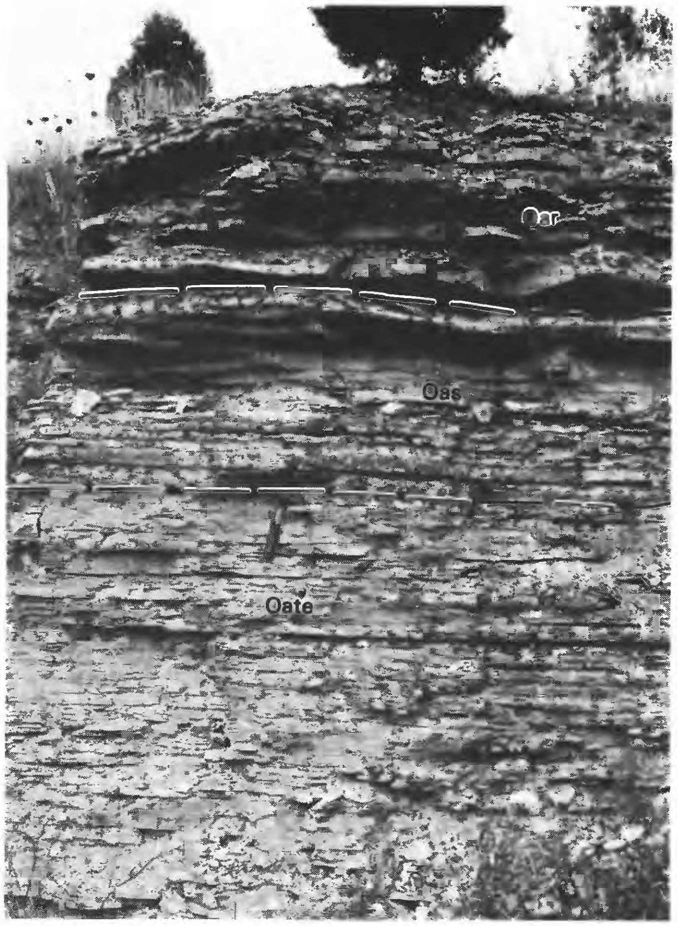

FIGURE 28.—Upper part of the Ashlock Formation at the type section (Weir and others, 1965, p. D29). The Terrill Member (Oate), chiefly laminated and very thin bedded dolomitic mudstone, is sharply overlain by micrograined limestone of the Sunset Member (Oas). The Reba Member (Oar) at top of outcrop is mostly nodular bedded fossil-fragmental limestone. Roadcut on U.S. Highway 27 about 3½ mi south of Lancaster, Lancaster quadrangle, southwestern east-central Kentucky.

The Terrill Member is a thin but persistent unit in east-central and southern central Kentucky (fig. 29). It ranges in thickness from 0 in the Bardstown and Maud quadrangles, western central Kentucky, and in the Preston quadrangle, northern east-central Kentucky, to about 35 ft in the Hedges quadrangle, east-central Kentucky.

Contacts at the top and base of the Terrill are generally sharp, but in places the rock types intergrade through several inches. The Terrill generally overlies the Stingy Creek Member or Grant Lake Member of the Ashlock Formation and is overlain by the Sunset Member of the Ashlock (fig. 28). In southwestern central Kentucky, it rests on the Grant Lake Limestone and is overlain by the Reba Member of the Ashlock. In southern central Kentucky, the Terrill and the Reba are thin inconspicuous units and were not separated from the Rowland Member of the Drakes Formation on most geologic quadrangle maps. The Terrill becomes more limy near Bardstown, Ky., and merges with the Grant Lake Limestone. To the south the Terrill passes into the Cumberland Formation, from which it is separated by cutoff at the north edge of the Dunnville quadrangle, northern south-central Kentucky. On the northeast the Terrill intertongues and intergrades with the Sunset Member of the Bull Fork Formation in the Preston quadrangle, northern east-central Kentucky (fig. 30).

SUNSET MEMBER

The Sunset Member was named by Foerste (1910, p. 18-19) for outcrops near the town of Sunset in the Hillsboro quadrangle, southeastern north-central Kentucky. The Sunset as used by Foerste (1910, 1912a) was a broadly conceived, in part faunally defined, lower member of the now-abandoned Arnheim Formation. Foerste and other earlier workers included in the Sunset fossiliferous limestone now assigned to the Bull Fork Formation and dolomitic to calcitic mudstone now assigned to the Terrill Member of the Ashlock Formation. Outerbridge (1970) defined the present use of the term "Sunset Member" by restricting it to micrograined limestone and shale similar to that cropping out in the type area near Sunset, Ky.

The Sunset Member consists of about 60 to 90 percent micrograined to fine-grained limestone and muddy limestone interbedded with minor shale. The micrograined to fine-grained limestone is generally pale olive, greenish gray, and medium gray, and weathers light gray. The muddy limestone is light greenish gray and weathers yellowish gray to grayish yellow. Most limestone is in continuous even, thin to medium beds, but much is in uneven and nodular beds. Ostracodes are common to abundant. Megafossils are sparse, but brachiopods, gastropods, and orthoconic cephalopods are locally conspicuous. The shale, greenish gray, generally calcitic and unfossiliferous, is in obscure to well-defined laminae in sets, a fraction of an inch to a few inches thick, interlayered fairly evenly with beds of limestone. The member is relatively resistant and commonly forms a ledgy slope.

The Sunset Member crops out around the east and south sides of the Blue Grass region of Kentucky (fig. 31), where it ranges from 0 to about 30 ft in thickness. The Sunset is classed as a member of the Bull Fork Formation in its type area in the Hillsboro quadrangle and in adjacent quadrangles, although in most of east-central Kentucky it is assigned to the Ashlock Formation because it lies between the Terrill and Reba Members of the Ashlock.

The lithology of the Sunset changes in northern east-central Kentucky (figs. 30, 32). Micrograined limestone that makes up approximately the lower third of the Sunset in the Owingsville quadrangle thins westward within the Preston quadrangle and merges with the underlying Grant Lake Member of the Ashlock Formation. Muddy limestone, dominant in the middle third of the Sunset in the Owingsville quadrangle, grades to dolomitic and calcitic mudstone in the western part of the Preston quadrangle, where it forms the northernmost recognizable strata of the Terrill Member of the Ashlock Formation. The upper third of the Sunset, composed mostly of micrograined nodular-bedded limestone, retains its lithologic character but thins gradually southward.

In northeast Kentucky, the Sunset Member is overlain by the upper part of the Bull Fork Formation and overlies the Grant Lake Limestone (pl. 7). Elsewhere it overlies the Terrill Member of the Ashlock Formation and is overlain by the Reba Member of the Ashlock (fig. 28). Contacts are sharp; zones of lithologic transition are rarely more than 6 in. thick.

The Sunset was not designated on geologic maps south of the Levee quadrangle, east-central Kentucky, but later studies have shown that the Sunset was included as a bed only a few feet thick in the Reba Member of the Ashlock Formation. This bed, here recognized as the Sunset Member, was described by Weir and others (1965, p. D24, D29) as unit 14a of the type section of the Ashlock Formation in the Lancaster quadrangle

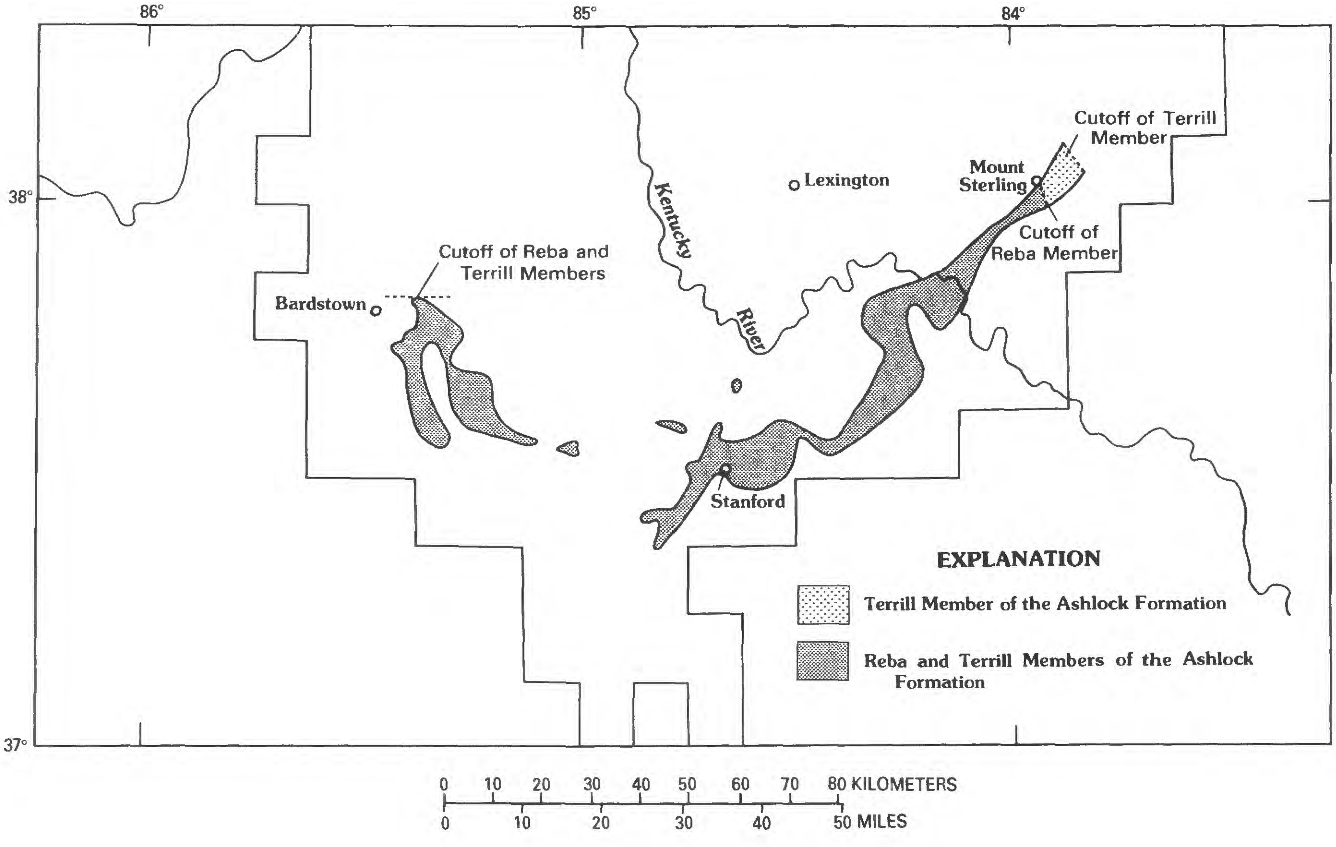

FIGURE 29.—Part of Kentucky, showing generalized area of outcrop of the Terrill and Reba Members of the Ashlock Formation.

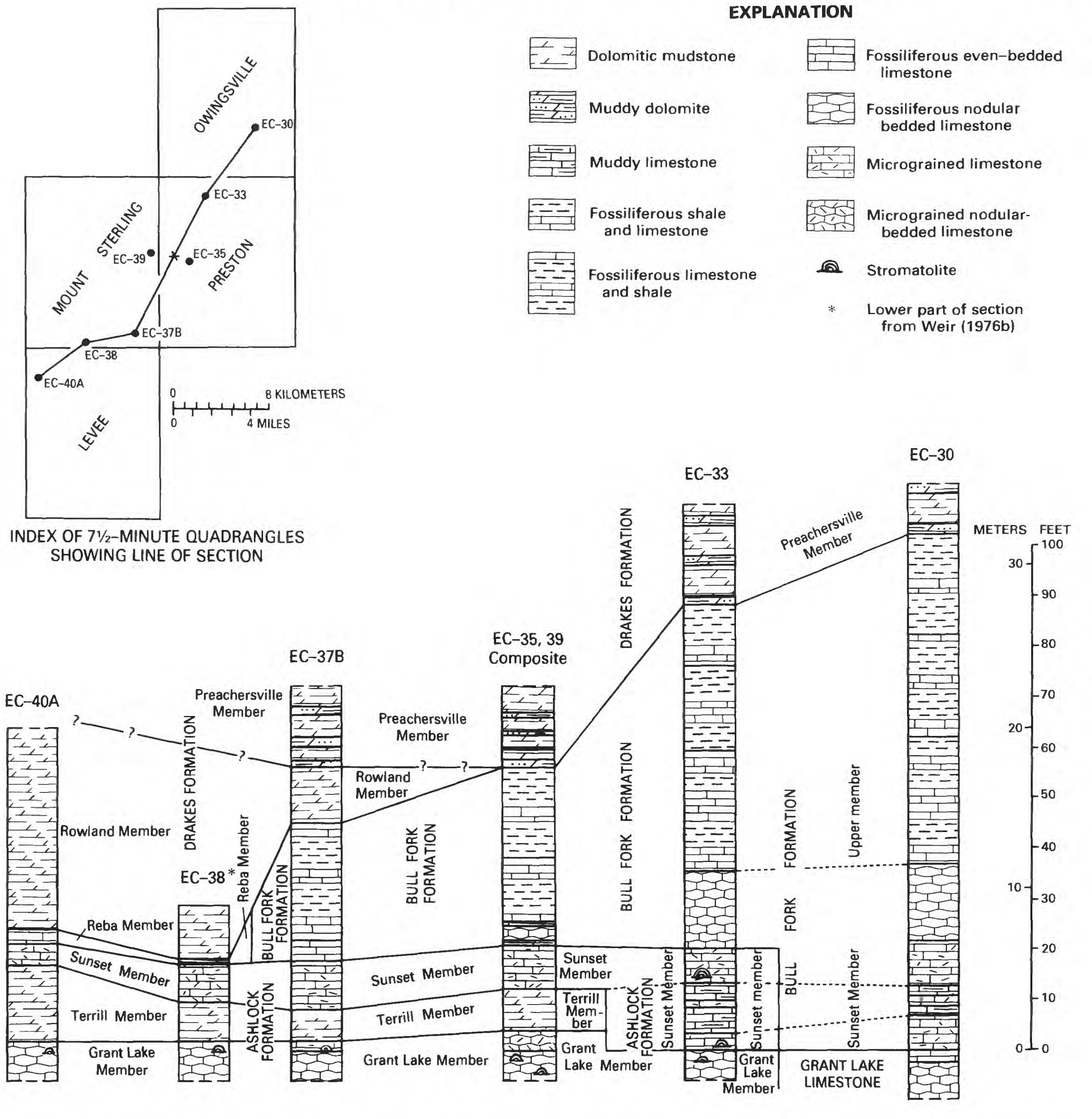

FIGURE 30.—Stratigraphic sections in Mount Sterling and adjoining quadrangles, northern east-central Kentucky, showing changes in the Ashlock, Bull Fork, and Drakes Formations (see table 2 for names of sections and additional data on locations). The Sunset Member is lower part of the Bull Fork Formation in Owingsville quadrangle and northward, and is in upper part of the Ashlock Formation in Preston quadrangle and southward. Micrograined lower part of the Sunset Member becomes more nodular, thins southwestward, and merges with the nodular-bedded Grant Lake Member of the Ashlock in Mount Sterling quadrangle. Muddy limestone and micrograined limestone of middle part of the Sunset become more muddy and dolomitic southwestward and near the west edge of Preston quadrangle are separated by arbitrary cutoff from dolomitic mudstone of the Terrill Member of the Ashlock Formation. Micrograined limestone forming upper part of the Sunset in Preston quadrangle constitutes whole thin member southwestward. Fossiliferous limestone and shale of the Bull Fork Formation also thins southwestward and is separated by cutoff in Mount Sterling quadrangle from similar limestone forming thin Reba Member of the Ashlock. The Rowland Member of the Drakes Formation pinches out northeastward near west edge of Preston quadrangle, probably in part by intertonguing and intergrading with the Preachersville Member of the Drakes Formation.

(fig. 28), and as unit 4a of the type section of the Reba Member in the Moberly quadrangle (secs. EC-2, EC-10, pl. 3). The Sunset pinches out to the southwest in the Yosemite quadrangle, northern south-central Kentucky, and in the Hustonville quadrangle, southeastern central Kentucky; it pinches out to the northeast in the Sherburne quadrangle, southern northeast Kentucky.

Reba Member

The Reba Member was named by Weir and others (1965, p. D13, D28-D29) for exposures near Lake Reba in the Richmond South and Moberly quadrangles, east-central Kentucky. The type section was described from roadcuts along Kentucky Highway 52 in the Moberly quadrangle (sec. EC-10, pl. 3).

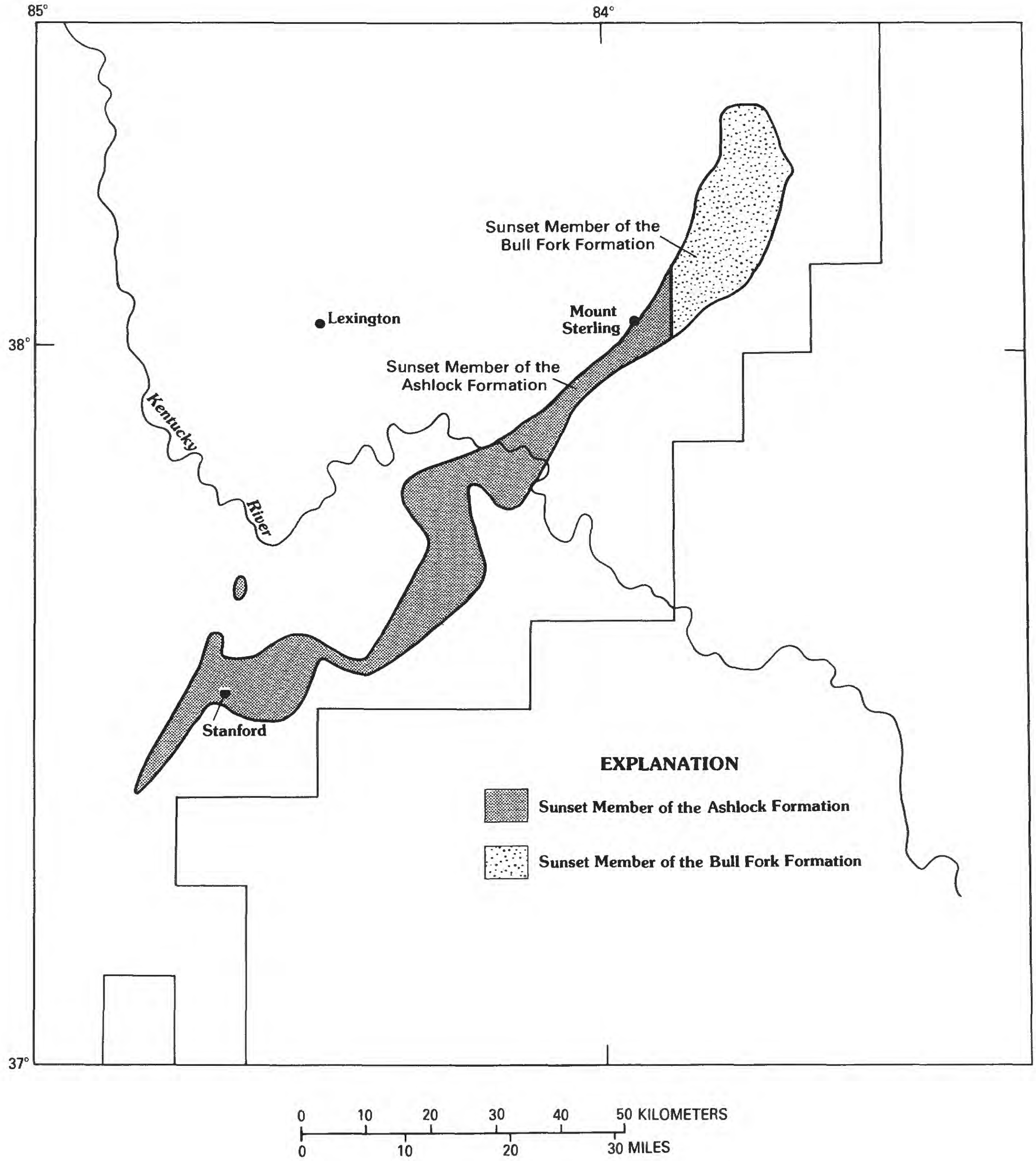

FIGURE 31.—Part of Kentucky, showing generalized area of outcrop of the Sunset Member of the Ashlock and Bull Fork Formations.

The Reba is composed mostly of fine- to medium-grained limestone containing streaks and partings of calcitic siltstone and silty shale. In southern east-central Kentucky, the upper part of the member commonly contains more shale, and the interbedded limestone is muddier. Both limestone and shale are commonly medium gray to olive gray and weather about the same or brownish gray. The member is characterized by fairly continuous but uneven nodular beds. Fossils are abundant; most conspicuous are large platystrophid and hebertellid brachiopods and large and small branching bryozoans. The Reba is fairly resistant and commonly forms a moderate slope that steepens toward the base.

The outcrop of the Reba Member extends throughout most of east-central and southern central Kentucky (fig. 29). The member ranges in thickness from about 1 to 25 ft; it is thinnest near its cutoffs in southwestern central and northeastern east-central Kentucky.

Contacts at the top and base of the Reba Member are relatively sharp; intergradations are commonly less than 6 in. The Reba is overlain by the Rowland Member of the Drakes Formation (fig. 33) and generally overlies the Sunset Member of the Ashlock Formation. West of the Hustonville quadrangle, the Reba rests on the Ter-

FIGURE 32.—Sunset Member of the Bull Fork Formation, showing threefold division of member in northern east-central Kentucky. Partly exposed lower third (L) is mostly nodular- and planar-bedded limestone that thins southwestward and merges with top of the Grant Lake Member of the Ashlock Formation near Mount Sterling. Middle third (M), composed of muddy limestone and medial set of micrograined limestone and shale beds, grades southwestward to dolomitic and calcitic mudstone of the Terrill Member of the Ashlock near Mount Sterling. Partly exposed upper third (U), lithologically like lower third, thins but persists southward, where it is classed as the Sunset Member of the Ashlock Formation. Note 1-ft rule in middle third of unit. Roadcut on Interstate Highway I-64 about 8 mi northeast of Mount Sterling, Preston quadrangle, east-central Kentucky.

FIGURE 33.—Contact between the Reba Member of the Ashlock Formation (Oar) and the Rowland Member of the Drakes Formation (Odr). Nodular-bedded limestone in lower third of photograph grades upward into calcitic shale containing nodules of fossiliferous limestone, which grades into a transitional layer of unfossiliferous dolomitic calcitic shale. Unfossiliferous dolomitic mudstone is at pick head and above. Roadcut at intersection of U.S. Highways 27 and 150, Stanford quadrangle, southeastern central Kentucky.

rill Member of the Ashlock (fig. 29). The upper contact is placed so as to include in the Reba the more calcitic transitional rocks—generally lenticles of fossiliferous limestone in calcitic mudstone. The basal contact is placed so as to exclude from the Reba throughgoing beds of micrograined and very fine grained limestone characteristic of the Sunset Member, or of dolomitic mudstone characteristic of the Terrill Member. However, on most geologic quadrangle maps of southwestern central Kentucky, a very thin Reba and underlying Terrill were included as an undifferentiated unit in the lower part of the Drakes Formation or in the upper part of the Grant Lake Limestone. Near Bardstown, southwestern central Kentucky, where the Terrill becomes more limy, both members merge with the adjoining and subjacent Grant Lake Limestone.

Southward from the outcrops in central Kentucky, the Reba apparently becomes more dolomitic and merges into the Cumberland Formation in northern south-central Kentucky. Sparsely fossiliferous dolomitic limestone at the probable stratigraphic level of the Reba is locally conspicuous in outcrops of the Cumberland in the Dunnville quadrangle and is probably continuous in the subsurface with the Reba Member of the Ashlock to the north.

On the northeast, the Reba Member of the Ashlock Formation thins markedly and grades into more planar-bedded limestone of the Bull Fork Formation. The cutoff separating the Reba from the Bull Fork is placed near long 83°55′ W. in the southeastern part of the Mount Sterling quadrangle, northern east-central Kentucky, where the Bull Fork averages less than 10 ft in thickness. Some details of stratigraphic changes in this part of the section near Mount Sterling are shown in figure 30.

BULL FORK FORMATION

The Bull Fork Formation was named by Peck (1966) for Bull Fork Creek, a small tributary of the Ohio River near Maysville in northeast Kentucky. The type section designated by Peck (1966, p. B16-B19, B26-B29) consists of roadcut exposures, now badly weathered, along Kentucky Highway 1443 in the Maysville East and Orangeburg quadrangles (sec. NE-1, pl. 1).

The Bull Fork is made up of very fossiliferous interlayered limestone and shale. The limestone content of the whole formation ranges locally from about 40 to 60 percent, but it is commonly about 80 percent near the base and decreases irregularly upward to only 20 percent near the top.

The limestone is light gray, medium gray, greenish gray, and bluish gray, and weathers light gray and yellowish gray. The limestone is mostly made up of whole and broken fossils, but because of differences in sorting, grain size, and bedding, it can be separated into four distinct types. Dominant is limestone made up of whole and broken fossils in a very fine grained to medium-grained matrix of fossil fragments and crystalline calcite, commonly containing streaks and patches of greenish-gray mudstone. This type of limestone generally forms rough-surfaced irregular planar beds, 1 to 8 in. thick. Also abundant is sparsely fossiliferous, in part muddy micrograined limestone in smooth-surfaced planar beds, 1 to 6 in. thick. Nodular-bedded limestone, similar to that characterizing the Grant Lake Limestone, is locally common in the lower part of the Bull Fork. This type of limestone consists of abundant whole and coarsely broken brachiopods and bryozoans in a poorly sorted muddy micrograined to medium-grained matrix of fossil fragments and microcrystalline to coarsely crystaline calcite. It is in irregular and discontinuous beds, mostly 2 to 3 in. thick, and weathers to yield a rubble of nodular fragments and whole fossils. Relatively rare but locally conspicuous is calcarenite made up of closely packed fairly well sorted fine to very coarse fossil debris in a fine- to medium-grained calcite matrix. The calcarenite is in even and lensing planar beds, as much as 18 in. thick, and in planar sets, as much as 24 in. thick, of low-angle crossbeds. Limestone near the top of the formation locally is irregularly dolomitized.

Microscopically, most limestone of the Bull Fork Formation is biomicrudite and consists of fossil material, about 0.1 to 30 mm across, that forms a grain-supported framework cemented by micrite and minor sparite (fig. 34). Sparry calcite also fills fossil cavities, such as zooecia of bryozoans and whorls and chambers of gastropod and cephalopod shells, and occurs as recrystallized shell material and recrystallized micrite. Dolomite occurs in micrite as scattered rhombs and patches of rhombs. Sparse pyrite is in minute grains and irregular patches and replaces trilobite fragments. Brown collophane is sparse as fillings of bryozoan zooecia and of pores in echinoderm plates, and as replacements of unidentified fossil fragments. Angular quartz silt, generally rare, is noticeable in biosparrudite and biosparite forming the beds of calcarenite.

Shale, which locally makes up as much as 60 percent of the Bull Fork and is everywhere dominant in the upper part of the formation, is medium gray to greenish gray. It is very calcitic and locally grades to muddy limestone; near the top of the formation the shale is in part dolomitic. Most of the shale is moderately fossiliferous, irregularly fissile, in crude to even laminae interlayered with limestone as partings and as even sets, whose average thickness increases upward in the formation from a few inches near the base to several feet near the top.

Fossils are abundant throughout the Bull Fork (pls. 1-5). Brachiopods and bryozoans are most numerous; large whole brachiopods are especially conspicuous on bedding planes. Other common fossils, mostly present as fragments, include gastropods, pelecypods, cephalopods, solitary and colonial corals, crinoids, trilobites, ostracodes, and stromatoporoids.

The Bull Fork is a nonresistant formation, which generally forms irregular moderate slopes littered with slabs of limestone. The slopes become gentler upward. Good exposures are restricted to streambanks and artificial cuts.

Subdivisions

The only named subdivision of the Bull Fork Formation is the Sunset Member (Outerbridge, 1970), described in a preceding section of this report as a member of the Ashlock Formation. The micrograined limestone and minor shale making up the Sunset in the type area in the Hillsboro quadrangle forms a conspicuous unit at the base of the Bull Fork in southern northeast Kentucky. The Sunset in part intergrades and pinches out in the Preston quadrangle, northern east-central Kentucky. West and south of the Preston quadrangle, because it is interlayered with members of the Ashlock Formation (fig. 30), the Sunset is classed as a member of the Ashlock Formation (pl. 7).

In and near the type area of the Bull Fork the top of a zone, as much as 20 ft thick, of abundant horn corals is a mappable horizon near the middle of the formation. In northern east-central Kentucky, as in the Owingsville quadrangle, the Bull Fork contains several continuous thin but lithologically distinct units of even-bedded muddy limestone and of nodular-bedded limestone. In general, however, the Bull Fork is a poorly exposed sequence of fossiliferous limestone and shale.

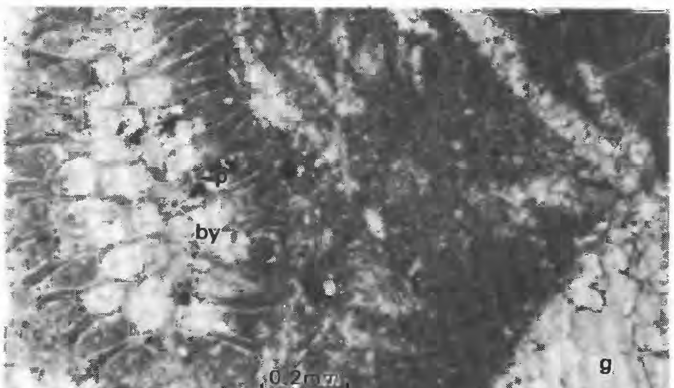

FIGURE 34.—Characteristic biomicrudite from the Bull Fork Formation, showing gastropod (g) and bryozoan (by) skeletal fragments in micrite. Opaque material is pyrite (p). Plane-polarized light.

Thickness and Stratigraphic Relations

The Bull Fork Formation crops out in a north-south-trending band, about 10 mi wide, on the northeast side of the Blue Grass region and extends northward into Ohio (fig. 35). At its type section the Bull Fork is slightly more than 200 ft thick. Southward, the formation thins gradually to about 100 ft a few miles north of the Mount Sterling quadrangle, northern east-central Kentucky, and then thins rapidly to about 10 ft at its cutoff in the Mount Sterling quadrangle (pl. 7). This progressive southward thinning of the Bull Fork is approximately matched by a thickening of the overlying Drakes Formation.

Along the outcrop on the northwest side of the Blue Grass region, the Bull Fork is more than 240 ft thick in the Madison West quadrangle, northwestern north-central Kentucky. East and northeast of the Madison West quadrangle the complete thickness of the formation is not preserved in Kentucky. To the north, in Indiana, the Bull Fork is included in the much thicker Dillsboro Formation. To the south it locally intertongues, thins rapidly, and finally grades out in the Simpsonville quadrangle, southwestern north-central Kentucky. Though uncertain because complete thicknesses of the Bull Fork are not present in much of north-central Kentucky, the southward thickening of the underlying Grant Lake Limestone seems to be at the expense of the basal part of the Bull Fork.

The Bull Fork Formation overlies the Grant Lake Limestone or the Grant Lake Member of the Ashlock Formation and is overlain by the Drakes Formation (pl. 7). Locally in north-central Kentucky, as in the Bedford quadrangle, the lower part of the formation intertongues with the Grant Lake Limestone. The basal contact is placed in a transitional zone, ranging from about 1 to 10 ft in thickness, so as to separate nodular-bedded muddy limestone of the Grant Lake from more planar bedded alternating limestone and shale of the Bull Fork. The lithology of the Bull Fork is irregularly transitional above into dolomitic shale and minor interbedded dolomite and dolomitic limestone of the Drakes Formation. The upper contact is placed at the top of the highest persistent fossiliferous limestone bed in a transitional zone, commonly a few feet thick.

On the east side of the Blue Grass region, the Bull Fork thins southward from the Ohio River to near-pinchout in northern east-central Kentucky, and grades to nodular-bedded limestone and is separated from the upper part of the Ashlock Formation by a cutoff in the Mount Sterling quadrangle. The Bull Fork also thins southward on the west side of the Blue Grass region. The upper part of the formation is separated from the lithologically similar Bardstown Member of the Drakes Formation by cutoff (cross sec. *A-A'*, pl. 7) in the Bedford quadrangle, western north-central Kentucky; the lower part intertongues with and grades into the Grant Lake Limestone in the Ballardsville quadrangle, southwestern north-central Kentucky.

DRAKES FORMATION

The Drakes Formation was named by Weir and others (1965, p. D16-D19, D30-31) for outcrops near the East Fork of Drakes Creek in the Paint Lick quadrangle, southwestern east-central Kentucky. The type section is exposed along and near a road connecting Preachersville and Cartersville in the southwestern part of the quadrangle. The formation consists of dolomitic to calcitic mudstone and lesser amounts of calcitic dolomite and dolomitic limestone. The Drakes crops out in a belt of irregular width along the outer edge of the Blue Grass region (fig. 36); its characteristic lithofacies extend into southeastern Indiana and southwestern Ohio. The formation ranges in thickness from about 20 ft in northeast Kentucky to about 150 ft in east-central Kentucky; in southern central Kentucky, it is locally cut out beneath a pre-Devonian unconformity. The Drakes is separated from similar strata in the upper part of the Cumberland Formation of south-central Kentucky by a cutoff at the north edge of the Dunnville quadrangle, northern south-central Kentucky.

The Drakes Formation includes four members, whose interrelations are shown in plate 7. At its type locality and in east-central Kentucky generally, the Drakes consists of the Rowland Member directly overlain by the Preachersville Member. In northeast Kentucky, the Drakes is represented by only the Preachersville Member. In most of central and north-central Kentucky, the formation consists of three members: the Rowland Member at the base; the Bardstown Member, a unit of fossiliferous limestone and shale; and the Saluda Dolomite Member at the top. In northern

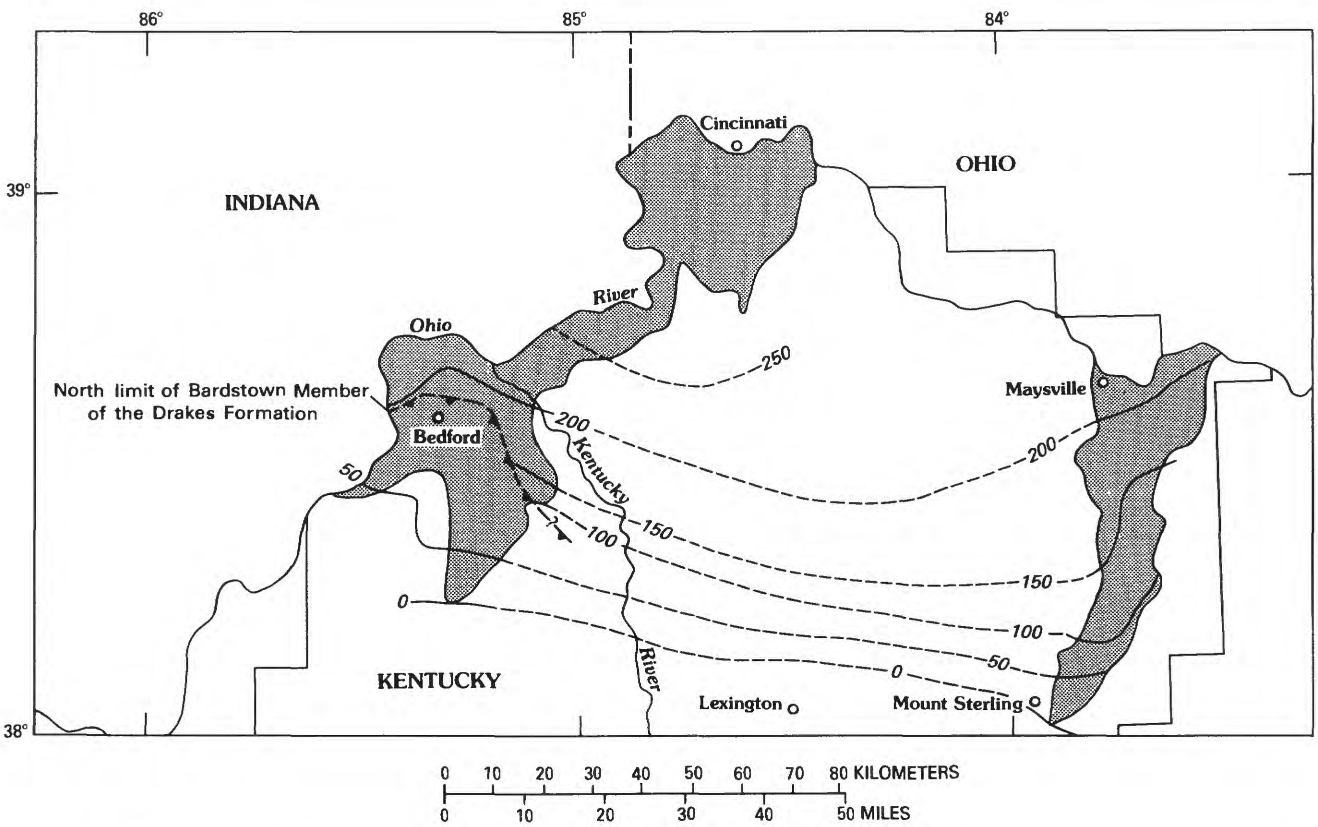

FIGURE 35.—Part of Kentucky, showing generalized area of outcrop (shaded) and thickness of the Bull Fork Formation. Contour interval, 50 ft; contours dashed where conjectural. North limit of the Bardstown Member of the Drakes Formation marks cutoff of tongue of strata lithologically similar to those of the Bull Fork Formation (see cross sec. *C-C'*, pl. 7).

north-central Kentucky, the Drakes is represented by only the Saluda Dolomite Member.

In northeast, most of north-central, and part of east-central Kentucky, the Drakes Formation overlies the Bull Fork Formation (pl. 7). In southwestern central Kentucky, it rests on the Grant Lake Limestone; in southeastern central and most of east-central Kentucky, it overlies the Ashlock Formation. The fossiliferous limestone and shale of the underlying units commonly grade through several inches to a few feet into dolomitic rocks characteristic of the Drakes.

In part of western central, in most of east-central, and in northeast Kentucky, the Drakes is overlain with seeming conformity by the Brassfield Dolomite (Formation) of Silurian age, but paleontologic studies reveal a hiatus between the formations (Rexroad and others, 1965, p. 12; Rexroad, 1967, p. 15-16; C. B. Rexroad, in Gray and Boucot, 1972, p. 1301). In north-central, southwestern central, and southwestern east-central Kentucky, physical evidence of post-Ordovician erosion is common. In these areas, the base of the Brassfield is irregularly wavy; amplitudes range from a few inches to

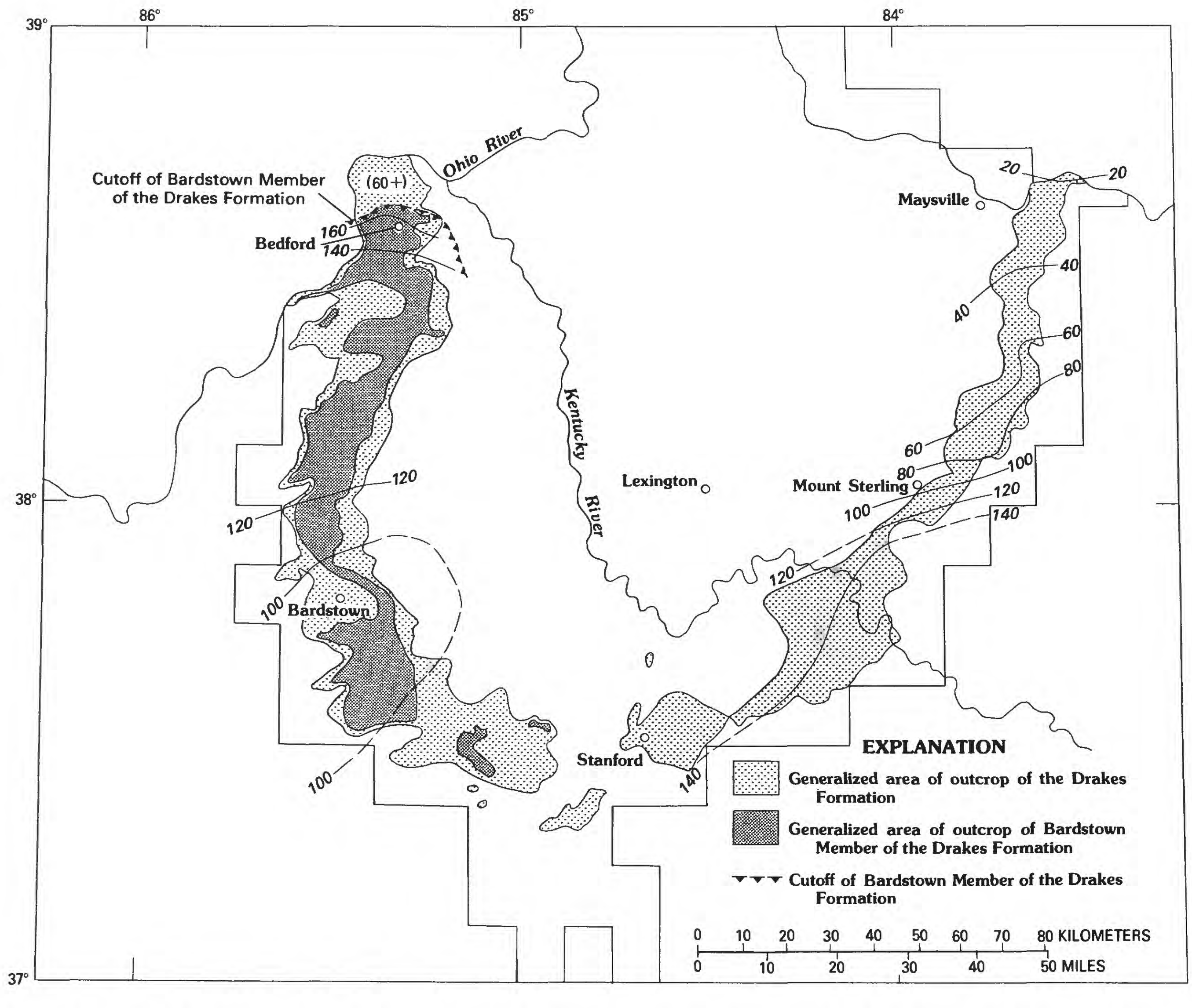

FIGURE 36.—Part of Kentucky, showing generalized area of outcrop of the Drakes Formation and its Bardstown Member, and thickness of the Drakes Formation. Contour, interval 20 ft; contours dashed where conjectural. Variations in thickness due to truncation by post-Ordovician unconformity not shown. The Bardstown Member is separated by cutoff from the lithologically similar Bull Fork Formation near Bedford; member is irregular in thickness, commonly about 40 to 60 ft thick in outcrops near Bedford, 25 to 45 ft thick between Bedford and Bardstown and 20 to 30 ft thick south and southeast of Bardstown. The Drakes Formation in Kentucky north of cutoff of its Bardstown Member ranges in thickness from about 65 to 75 ft.

about a foot. Clasts derived from the Drakes are incorporated into basal beds of the Brassfield locally in north-central Kentucky (Gauri and others, 1969, p. 1882) and in southwestern east-central Kentucky (fig. 37). Relations in southern central Kentucky are more complex (figs. 7, 8): The Drakes is locally overlain unconformably by the Brassfield or by the Boyle Dolomite of Middle Devonian age or by the New Albany Shale of Middle and Late Devonian age. In places the unconformity is angular (Jillson, 1956, p. 99); the maximum discordance noted is about 4° in the Hustonville quadrangle, southeastern central Kentucky (fig. 9). As shown in figure 7, the Drakes Formation locally is entirely cut out beneath Devonian strata.

Rowland Member

The Rowland Member of the Drakes Formation was named by Weir and others (1965, p. D17, D32-D33) for outcrops near the town of Rowland in the Stanford quadrangle, southeastern central Kentucky. The type section is exposed along U.S. Highway 27 about 1.3 mi west of Rowland.

In east-central and most of central Kentucky, the member consists of calcitic to dolomitic mudstone locally grading to muddy micrograined limestone or dolomite. Figure 5 plots the calculated mineralogic composition of representative samples of mudstone from the Rowland. The mudstone is grayish green, olive green, or light gray, weathers yellowish gray, and in places contains sparse but conspicuous spots, streaks, and small patches of an unidentified light-green clay mineral. The member is obscurely laminated and very thin bedded and locally contains ripple marks and mud cracks (fig. 38). Megafossils are absent.

In western central Kentucky, north of the Bardstown quadrangle, and in north-central Kentucky, although the general aspect of the member is unchanged, the Rowland becomes more calcitic. The dominant rock types are micrograined to medium-grained limestone and dolomitic limestone and calcitic mudstone. The limestone and dolomitic limestone, which are mostly olive gray and weather yellowish gray to yellowish orange, occur in laminae and even to uneven thin to medium beds, as much as 30 in. thick, intercalated with partings and thin to thick sets of olive-gray and greenish-gray calcitic mudstone. Some mudstone is dark gray and carbonaceous. Fossils, generally sparse but in places abundant, are dominantly brachiopods, bryozoans, ostracodes, and gastopods; in north-central Kentucky, colonial corals are conspicuous.

Microscopically the more dolomitic Rowland is composed of euhedral dolomite, anhedral calcite, unidentified clay minerals, fossil fragments, angular quartz,

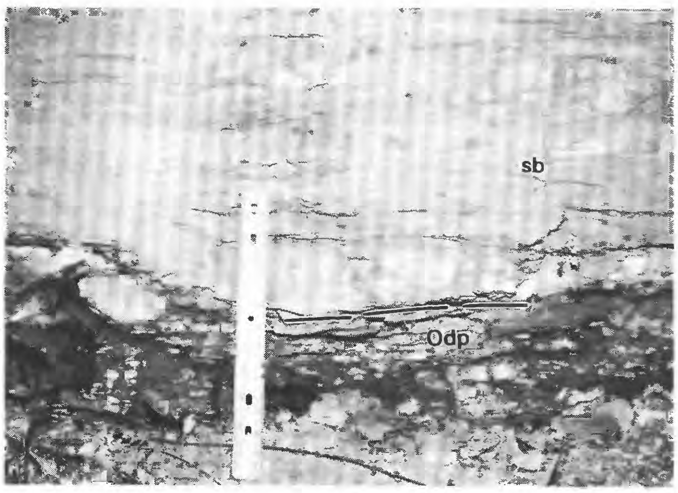

FIGURE 37.—Basal part of The Brassfield Dolomite (Formation) (Sb), containing clasts (light-gray patches) derived from the underlying Preachersville Member of the Drakes Formation (Odp). Exposed Brassfield is fine- to medium-grained dolomite; exposed Preachersville is dolomitic mudstone. Unconformity marked by dashed line. Exposed part of ruler is 11 in. long. Old roadcut on east side of U.S. Highway 25 about 2 mi north of Berea, Berea quadrangle, southwestern east-central Kentucky.

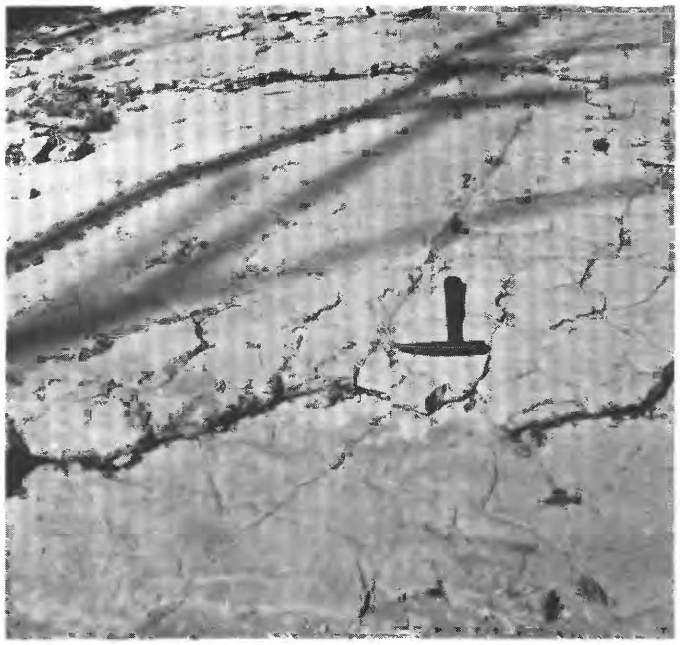

FIGURE 38.—Fossil mud cracks in micrograined limestone of the Rowland Member of the Drakes Formation. Faint ripple marks are visible on bed in foreground. Outcrop in Followell Creek, Gravel Switch quadrangle, southern central Kentucky.

opaque organic(?) material, and pyrite. Nearly all particles are between 10 and 100µm across. Dolomite rhombs are dominant. Fragments recognizable as bioclastic are lath shaped and sparse. The content of quartz silt ranges from near 0 to about 25 percent.

Study of thin sections of the more calcitic Rowland shows that it is characteristically composed of a groundmass of obscurely pelleted to clotted micrite and microspar containing scattered fossil fragments and dolomite rhombs. Small clusters of sparry calcite, probably fillings of burrows and recrystallized shell material, are scattered through the rock. A green clay mineral occurs in patches and as fillings of burrows. Pyrite is sparse.

The Rowland is relatively nonresistant and generally forms fairly uniform gentle to moderate slopes that contrast with the more irregular slightly steeper slopes formed by underlying and overlying units.

Thickness and Stratigraphic Relations

The Rowland Member crops out around the Blue Grass region of Kentucky from near the Ohio River in north-central Kentucky to northeastern east-central Kentucky (fig. 39). The member ranges from 0 to about 65 ft in thickness and is locally cut out by pre-Devonian erosion in southern central Kentucky.

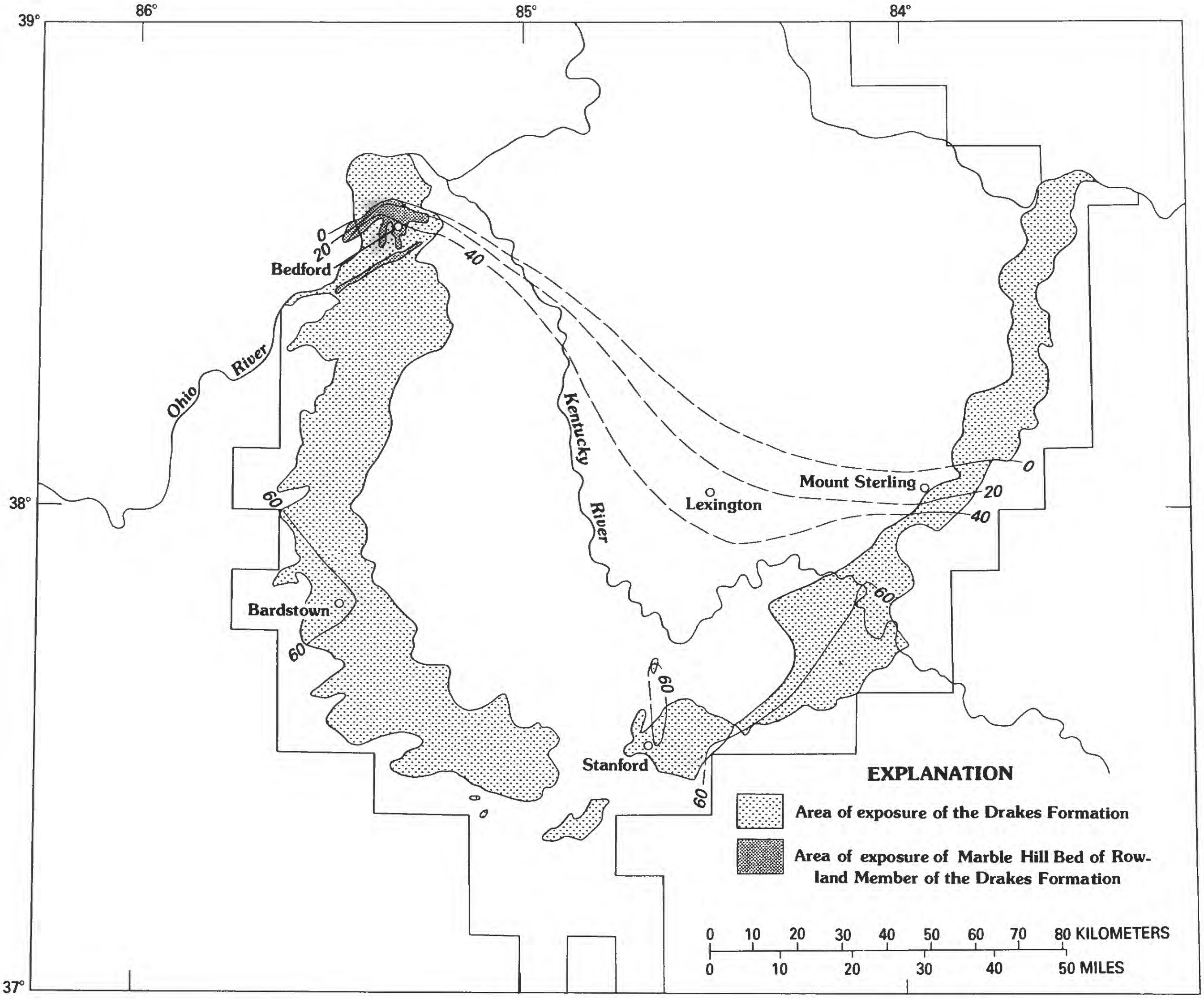

FIGURE 39.—Part of Kentucky, showing generalized area of outcrop of the Drakes Formation and of the Marble Hill Bed of its Rowland Member, and thickness of its Rowland Member. Contour interval, 20 ft; contours dashed where conjectural. Variations in thickness due to truncation by post-Ordovician unconformity not shown. Northwest edge of the Marble Hill Bed coincides generally with edge of the Rowland Member.

In northwestern north-central Kentucky, the Marble Hill Bed, a minor subdivision of the Rowland, lies near the pinchout of the member (figs. 40, 41). The unit was named by Owen (1859, p. 28-29) for quarry exposures at Marble Hill near Madison, Ind., and lies within strata included in the Dillsboro Formation by Brown and Lineback (1966). In Kentucky, the Marble Hill Bed was assigned to the Rowland Member of the Drakes Formation by Swadley and Gibbons (1976). The characteristic lithology is light-gray poorly sorted fine- to coarse-grained bioclastic limestone in irregular to even beds, as much as 3 ft thick, and in thin crossbeds in sets, 1 to 3 ft thick. Whole and broken fossils are abundant; dominant are gastropods, crinoids, brachiopods, and bryozoans; less common are pelecypods, cephalopods, and corals. The Marble Hill Bed is a ledge-forming unit consisting of several lensing bodies that range stratigraphically from the top to the base of the Rowland Member. The maximumaggregate thickness of the Marble Hill Bed is about 30 ft.

In north-central and most of central Kentucky, the Rowland Member of the Drakes Formation is overlain by the Bardstown Member of the Drakes. In northern north-central Kentucky, the Rowland overlies the Bull Fork Formation. In southern north-central and western central Kentucky, the member rests on the Grant Lake Limestone. In east-central and southeastern central Kentucky, it overlies the Ashlock Formation (fig. 33) and is overlain by the Preachersville Member of the Drakes Formation. In north-central Kentucky, the Rowland becomes generally more limy and fossiliferous northward, and west of Madison, Ind., it passes into the Dillsboro Formation of Brown and Lineback (1966). It thins northeastward and pinches out in the Bedford quadrangle, northwestern north-central Kentucky, in lithology characteristic of the Bull Fork Formation. In northern east-central Kentucky, the Rowland thins and pinches out or grades into lithology characteristic of the Preachersville Member of the Drakes Formation. These stratigraphic relations are shown in plate 7.

The contacts of the Rowland are fairly sharp. The lithology of the Rowland is transitional through a few inches to several feet with fossiliferous muddy limestone of the underlying Grant Lake Limestone and the Ashlock and Bull Fork Formations. The basal contact is placed at the top of the zone of transition so as to exclude fossiliferous calcitic mudstone and fossil-fragmental muddy limestone from the Rowland (fig. 33). In central and north-central Kentucky, the lithology of the Rowland is also transitional with the overlying Bardstown Member; the contact is placed at the base of the zone of transition.

In east-central Kentucky, the contact with the overlying Preachersville Member, though in a few places indistinct, is commonly marked by a ledge of fine- to medium-grained dolomite or dolomitic limestone. In southern central Kentucky, the Rowland is locally overlain unconformably by the Boyle Dolomite or the New Albany Shale of Devonian age; in a few places, the member has been entirely removed by pre-Devonian erosion (see fig. 6).

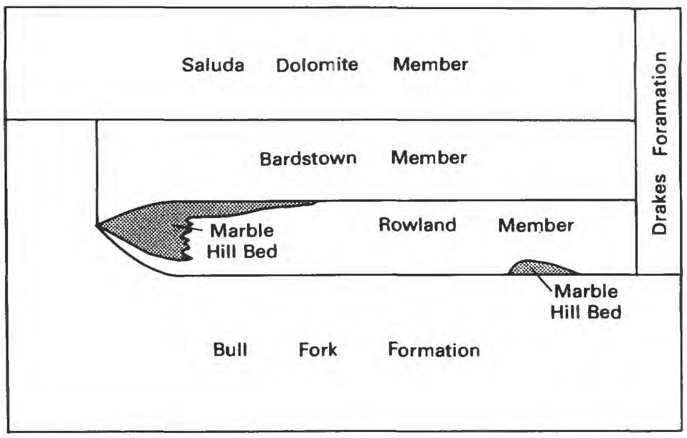

FIGURE 40.—Stratigraphic relations of the Marble Hill Bed of the Rowland Member of the Drakes Formation, northwestern north-central Kentucky.

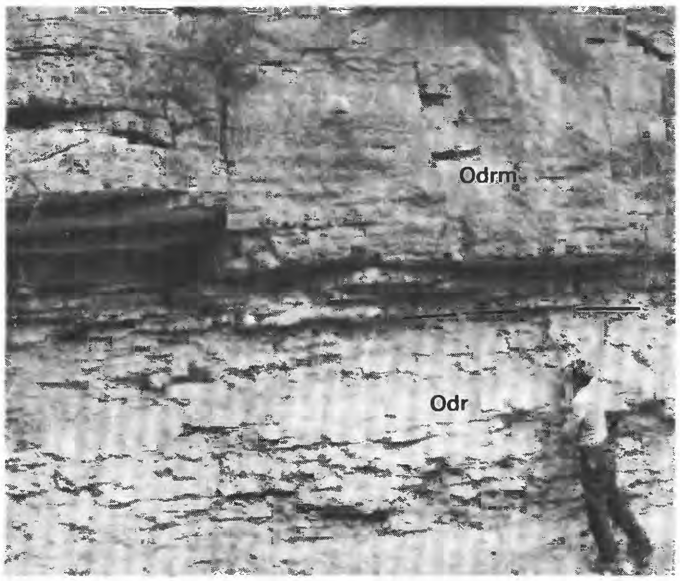

FIGURE 41.—Upper part of the Rowland Member of the Drakes Formation, showing ledge-forming Marble Hill Bed (Odrm), composed of bioclastic limestone consisting of abundant whole and broken gastropods in a calcarenite and sparite matrix. Below is calcitic mudstone and medium-grained limestone (Odr) that forms bulk of the Rowland in western central and north-central Kentucky. Roadcut on U.S. Highway 42 about 2 mi east of Bedford, Bedford quadrangle, western north-central Kentucky.

Preachersville Member

The Preachersville Member of the Drakes Formation was named by Weir, Greene, and Simmons (1965, p. D18, D33-D35) for outcrops near Preachersville in the Lancaster quadrangle, southwestern east-central Kentucky. The type section is exposed along Kentucky Highway 39 about 2 mi southeast of Preachersville (sec. EC-1, pl. 3).

The member consists of dolomitic to calcitic mudstone, dolomite, and dolomitic limestone. The mudstone locally grades to very muddy dolomite. Figure 5 plots the calculated mineralogic composition of representative samples of mudstone from the Preachersville. The mudstone is generally similar to the previously described mudstone of the Rowland Member of the Drakes Formation. The fresh rock is dominantly light grayish green, but in northeastern northeast Kentucky, as in the Tollesboro quadrangle, some mudstone near the top of the member is reddish purple.

The Preachersville differs from the underlying Rowland in containing beds of fine- to medium-grained dolomitic limestone or calcitic dolomite that make up about 10 to 25 percent of the member. These rocks generally contain clay and silt; locally the calcitic dolomite grades to dolomitic mudstone. The fresh rocks are dominantly grayish green or yellowish gray and mostly weather grayish yellow and grayish orange. The beds, which range from about 1 to 8 in. in thickness, are interstratified in the member as single beds and grouped in sets as much as 5 ft thick. The thicker beds and sets are more common near the base of the member. The member is generally nonresistant and crops out poorly. Because the beds and sets of dolomite and dolomitic limestone form ledges, the Preachersville is characterized by more irregular slightly steeper slopes than the underlying Rowland Member.

Fossils are generally absent or very sparse in the Preachersville, although poorly preserved small branching bryozoans and lesser amounts of small brachiopods are common in some beds of calcitic dolomite and dolomitic limestone. Locally in southern east-central Kentucky, large colonial corals and stromatoporoids are common to abundant in basal layers of the Preachersville. North and northeast of Richmond, Ky., abundant corals and stromatoporoids characterize a lithologic unit, the Otter Creek coral bed of the Preachersville Member (Simmons and Oliver, 1967).

Thickness and Stratigraphic Relations

The Preachersville Member of the Drakes Formation is the topmost unit of the Ordovician section in east-central and northeast Kentucky. The member attains a maximum thickness of about 100 ft near Richmond, east-central Kentucky, and thins northward along the outcrop to less than 20 ft near the Ohio River (fig. 42). Although the distribution and thickness of the Preachersville in Ohio is uncertain, the characteristic lithofacies of the member is present at Ohio Brush Creek, about 22 mi northeast of Maysville, Ky. (Schmidt and others, 1961, p. 281, 282; Kohut and Sweet, 1968, p. 1459), and at least as far north as Huffman Dam, 4 mi east of Dayton, where it is about 55 ft thick (Weir, Peterson, and Swadley, 1979d). In southern central Kentucky, the Preachersville grades westward, mostly in the subsurface, into the Saluda Dolomite Member of the Drakes Formation. In northern south-central Kentucky, the Preachersville has been mostly removed by pre-Devonian erosion, but it apparently grades southward in the subsurface into the upper part of the Cumberland Formation.

The Preachersville Member conformably overlies the Rowland Member of the Drakes Formation in most of east-central Kentucky. The contact is generally marked by a conspicuous ledge-forming set of even beds of fine- to medium-grained dolomite or dolomitic limestone, although locally, as near Richmond, Ky., the members intergrade, and so their division is indistinct. In northern east-central and northeast Kentucky, the Preachersville constitutes the whole of the Drakes Formation and rests on the Bull Fork Formation; the contact is placed at the top of a gradational zone of dolomitic to calcitic mudstone containing lenticles and partings of fossiliferous limestone.

Throughout most of its extent the Preachersville Member of the Drakes Formation is overlain with seeming conformity by the Brassfield Dolomite (Formation) of Early Silurian age, although studies of conodonts suggest a considerable break in deposition (Rexroad and others, 1965, p. 12). Physical evidence of an unconformity is common in southern east-central Kentucky. In places, beds in the Preachersville are truncated, and locally the Brassfield contains clasts of dolomitic mudstone and dolomite torn from the underlying Preachersville (fig. 37). In southeastern central and northern south-central Kentucky the Preachersville has been deeply eroded and locally cut out by pre-Devonian erosion. Where present, the member is unconformably overlain by the Boyle Dolomite of Middle Devonian age or by the New Albany Shale of Middle and Late Devonian age.

Bardstown Member

The Bardstown Member of the Drakes Formation is absent in the type area of the Drakes. The member was named by Peterson (1970) for outcrops near Bardstown in western central Kentucky. The type section is exposed in roadcuts along U.S. Highway 150, about 7 mi east of Bardstown in the Maud quadrangle (sec. C-14, pl. 4).

The Bardstown in the type area consists of muddy limestone, fossil-fragmental limestone, and calcitic shale. The muddy limestone is gray to greenish gray, contains sparse to abundant whole and broken fossils, and is in lensing beds, commonly 1 to 8 in. thick. Less abundant is medium-gray bioclastic limestone composed of whole fossils and fine to coarse fragments of fossils in a micrograined to coarse-grained calcite matrix. The bioclastic limestone is interlayered with the muddy limestone in fairly resistant thin beds, lenses, and nodules, mostly 0.5 to 3 in. thick.

Fossils are abundant in typical rocks of the Bardstown. Colonial corals, as much as 4 ft across, are the most conspicuous forms (fig. 43); they are generally concentrated in two to four layers in the middle two-thirds of the unit. Brachiopods are abundant throughout; horn corals, bryozoans, pelecypods, and gastropods are very common.

The lithology of the Bardstown changes northward from the type area: fossil-fragmental limestone becomes

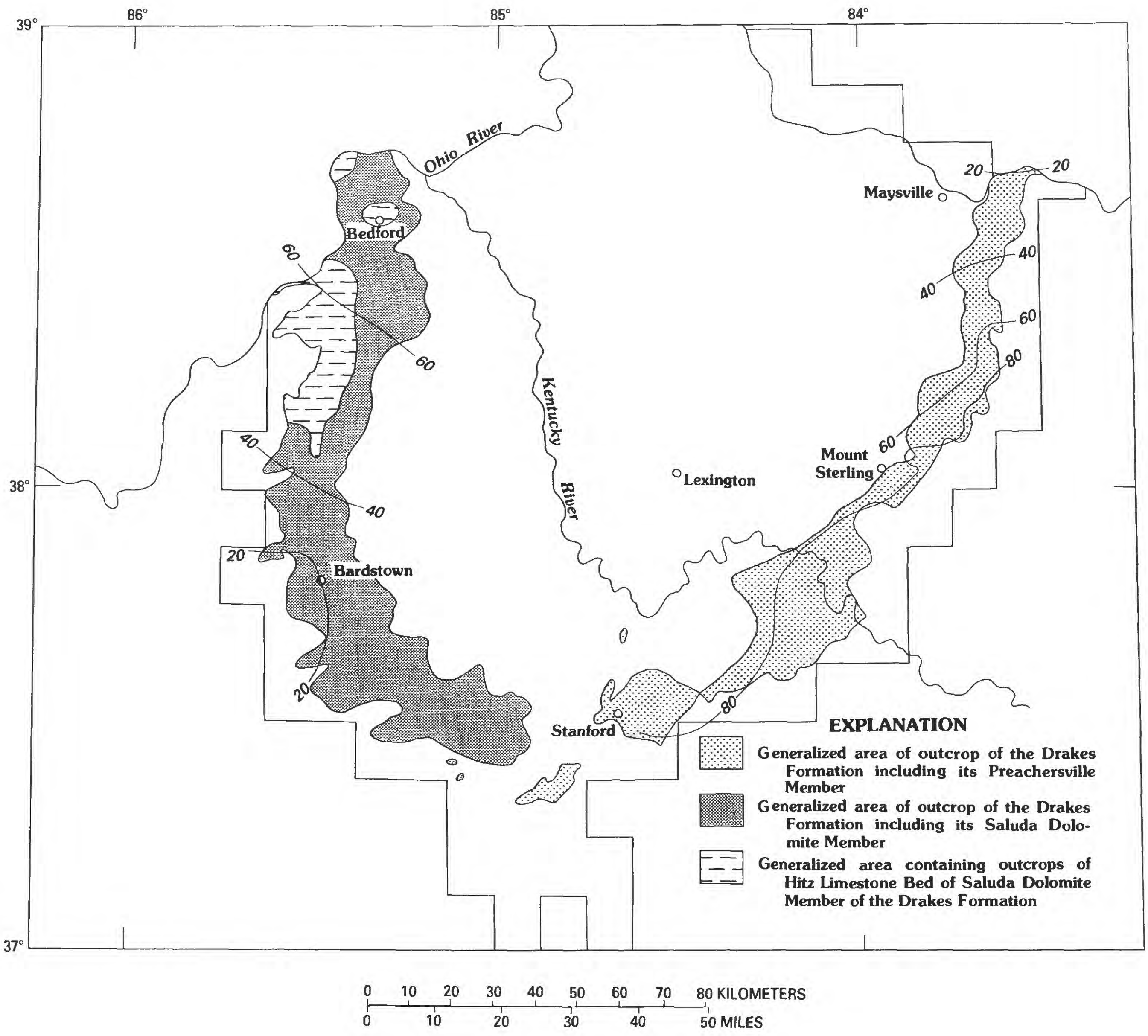

FIGURE 42.—Part of Kentucky, showing generalized area of outcrop of the Drakes Formation and thickness of its Preachersville and Saluda Dolomite Members, and generalized area containing discontinuous outcrops of the Hitz Limestone Bed of the Saluda. Contour interval, 20 ft; contours dashed where conjectural. Variations in thickness due to truncation by post-Ordovician unconformity not shown.

dominant, interbeds of gray calcitic shale become more abundant, and the percentage of muddy limestone decreases. The member remains very fossiliferous, but colonial corals decrease in abundance northward and are not present near the north limit of the Bardstown in the Bedford quadrangle, western north-central Kentucky.

Microscopically, most limestone in the Bardstown Member is biosparrudite or biomicrudite. Dominant is limestone made up of closely packed poorly sorted whole fossils and fossil fragments, ranging from about 0.1 to 30 mm across, which form a grain-supported framework cemented by sparry calcite or by sparry calcite and lesser micrite. Less common is limestone containing similar, but more loosely packed, fossil material in a matrix of micrite. Sparry calcite also fills fossil cavities and occurs as recrystallized shell material. Dolomite occurs as small irregular patches of subhedral crystals, apparently replacing micrite, and as small rhombs scattered in micrite. The fossil fragments are of the megafossils noted above and also of crinoid plates and trilobites. Minor chert and sparse pyrite replace shell fragments.

Thickness and Stratigraphic Relations

The Bardstown Member crops out in a narrow north-south-trending band on the west side of the Blue Grass region (fig. 36). The member is about 20 to 35 ft thick in the type area and thickens irregularly northward to a maximum of about 60 ft in the Bedford quadrangle, western north-central Kentucky. The Bardstown thins slightly southward and apparently grades out or pinches out in the subsurface in southeastern central Kentucky, south of the Bradfordsville quadrangle and east of the Parksville quadrangle.

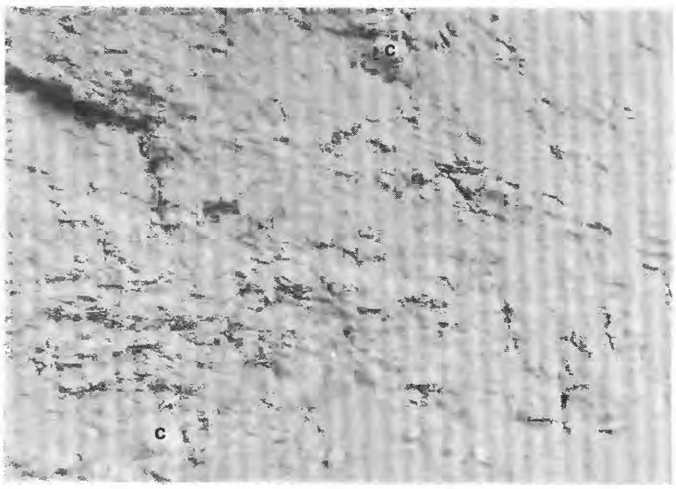

Figure 43.—Bardstown Member of the Drakes Formation at type section of member. Zones of abundant coral heads (c) are visible at level of pick (lower left) and near top of photograph. Roadcut on U.S. Highway 150, about 1.5 mi northwest of Fredericktown, Maud quadrangle, western central Kentucky.

The Bardstown conformably overlies the Rowland Member of the Drakes Formation and generally is conformably overlain by the Saluda Dolomite Member of the Drakes. Locally in southern central Kentucky, the Bardstown is unconformably overlain or cut out by post-Ordovician units (see figs. 7, 8). The basal contact is commonly indefinite and is placed in a gradational sequence, a few feet thick, so as to include all lenses of fossiliferous limestone in the Bardstown Member. In places near its north limits, the basal contact of the Bardstown is sharply defined by a calcarenite unit, the Marble Hill Bed, at the top of the Rowland Member. The upper contact is sharp in places but more commonly is placed in a zone of transitional lithology so as to include the highest persistent bed of limestone in the Bardstown.

The south and southeast limits of the Bardstown Member are in the subsurface. South of outcrops in the Bradfordsville NE and adjoining quadrangles, southern central Kentucky, the Bardstown passes into dolomitic rocks of the Cumberland Formation. East of outcrops of the member in the Parksville quadrangle, southeastern central Kentucky, the Bardstown is absent at the surface. Sporadic occurrences of colonial corals near the base of the Preachersville Member of the Drakes Formation suggest that calcitic rocks of the Bardstown grade eastward into dolomitic rocks of the Preachersville.

On the north the Bardstown Member merges with the lithologically similar Bull Fork Formation where the underlying Rowland Member of the Drakes Formation pinches out. The Bardstown is cut off at the pinchout of the Rowland in the Bedford, Bethlehem, and Campbellsburg quadrangles, western north-central Kentucky (pl. 7). The Bardstown was designated a member of the Drakes Formation because in its type area it is overlain and underlain by other members of the Drakes. Subsequent mapping showed that the Bardstown may also be viewed as a tongue of the Bull Fork Formation that extends more than 90 mi south of the main body of the Bull Fork.

Saluda Dolomite Member

The name "Saluda," drawn from Saluda Creek in southeastern Indiana, was given by Foerste (1902, p. 369) to a unit of dolomite containing minor limestone and shale exposed at Madison, southeastern Indiana. In Kentucky, the Saluda is chiefly very fine grained dolomite, in part muddy and in part calcitic. Figure 5 plots the calculated mineralogic composition of representative samples of the Saluda. The fresh rock is commonly light olive gray to greenish gray; it weathers yellowish gray to dark yellowish orange, locally mottled a darker gray.

The member is divided into subequal parts (fig. 44); the upper part commonly is thicker than the lower part. In much of north-central and western central Kentucky, this division is marked by a persistent layer, a few inches to about a foot thick, of olive- to dark-gray carbonaceous calcitic shale (Hatfield, 1968, p. 7, pl. 1). The upper part of the Saluda is micrograined to medium-grained calcitic dolomite in obscure laminae and very thin beds. A light-green clay mineral is locally conspicuous as spots, streaks, and small patches. Fossils are virtually absent except for sparse broken brachiopods and bryozoans in the more calcitic layers near the top and base. Ripple marks, mud cracks, and trace fossils occur on some bedding planes. At the top of the member in western north-central Kentucky is the discontinuous Hitz Limestone Bed. This unit, as much as 20 ft thick, was named by Foerste (1903, p. 347) for typical exposures on Hitz Hill near Madison, Ind. The Hitz is made up of resistant thin irregular beds of greenish-gray micrograined to medium-grained limestone interlayered with minor shale; fossils include ostracodes, gastropods, brachiopods, and colonial corals.

The lower part of the Saluda contains more silt and clay than the upper part and consists of dolomite, calcitic dolomite, dolomitic mudstone, dolomitic limestone, and limestone. The dolomite and calcitic dolomite, similar to those in the upper part of the member, are in layers a few inches to about 18 in. thick, interbedded and intergrading with dolomitic mudstone. The mudstone is less resistant than other rocks in the formation. The dolomitic limestone and limestone are fine to coarse grained and locally contain whole and broken fossils, mostly brachiopods and branching bryozoans and, in places, colonial corals. The upper part of the member commonly forms a prominent ledge and a bench dotted with small sinks; the less resistant lower part forms an irregular moderate slope.

Microscopically (fig. 45) dolomite of the Saluda is composed of dolomite rhombs 20 to 75 μm across, anhedral calcite crystals 10 to 30 μm across, angular quartz grains 10 to 30 μm across, clay minerals in thin sheaths along crystal boundaries, and sparse to common pyrite and opaque organic(?) material in irregular grains 20 to 50 μm across. Identifiable fossil fragments are virtually absent. As suggested in figure 5 and table 3, the lower part of the Saluda probably contains on average about 10 percent more clay and silt than the upper part, although microscopically the upper and lower parts are much alike. The lamination in the Saluda results from layered differences in the concentration of dolomite rhombs (Hatfield, 1968, p. 7), in the sizes of dolomite rhombs, and, to a lesser extent, in the concentration of opaque minerals, clay material, and quartz silt.

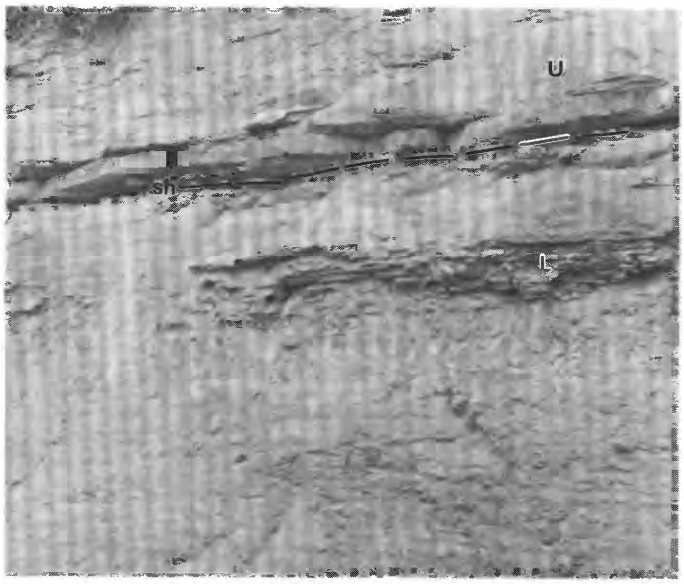

FIGURE 44.—Saluda Dolomite Member of the Drakes Formation, showing division into upper and lower parts. Upper part (U) is chiefly very fine grained dolomite; lower part (L) is very fine grained muddy dolomite and dolomitic mudstone. Thin layer of dark-gray shale (sh) marks division. Roadcut on Kentucky Highway 1694 about 2.5 mi south of Skylight, Owen quadrangle, western north-central Kentucky. Bed above shale is about 1 ft thick.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Saluda Dolomite Member of the Drakes Formation crops out around the west and south sides of the

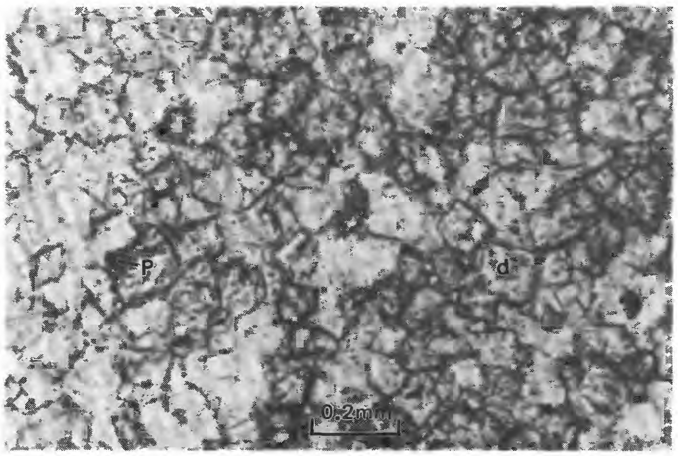

FIGURE 45.—Calcitic dolomite from upper part of the Saluda Dolomite Member of the Drakes Formation. Dominant are euhedral crystals of dolomite (d), rimmed with a green clay mineral. Interstitial material is mostly light-gray calcite and minor clay and silt. Scattered opaque grains are pyrite (p). Plane-polarized light.

Blue Grass region of Kentucky. The member ranges in thickness from a pre-Devonian erosional edge in southern central Kentucky to about 70 ft in northwestern north-central Kentucky (fig. 42).

The Saluda Dolomite Member of the Drakes Formation is overlain throughout most of its extent by the Brassfield Dolomite (Formation) of Silurian age (figs. 7, 8, 46). Studies of conodonts indicate that the contact is an unconformity (Rexroad, 1967, p. 15-16), although evidence of post-Ordovician erosion is generally inconspicuous. Rarely, however, fragments of the Hitz Limestone Bed of the Saluda are incorporated into Silurian strata (Gauri and others, 1969, p. 1883) in the Owen quadrangle, western north-central Kentucky. In southern central Kentucky, the Saluda is unconformably overlain locally by the Boyle Dolomite or the New Albany Shale of Devonian age.

The Saluda through most of its extent overlies the Bardstown Member of the Drakes Formation; in northwestern north-central Kentucky, it rests on the Bull Fork Formation. The lithology of the basal part of the Saluda is transitional with the Bardstown and Bull Fork. The contact is placed at the base of the dolomitic strata so as to exclude persistent beds of fossiliferous limestone from the Saluda.

The Saluda Dolomite Member apparently grades eastward in the subsurface into the Preachersville Member of the Drakes Formation in east-central Kentucky and southward into the upper part of the Cumberland Formation in south-central Kentucky. In Indiana, the Saluda thins northward from a thickness of about 60 ft near the Ohio River to pinchout about 45 mi north of the river (Brown and Lineback, 1966, p. 1020; Hatfield, 1968, pl. 1).

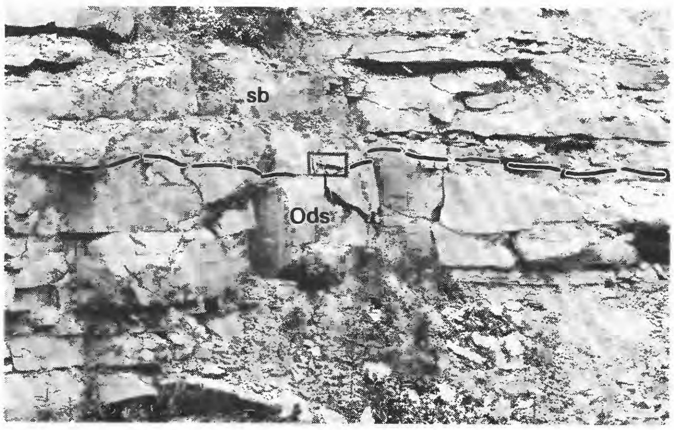

FIGURE 46.—Contact between the Saluda Dolomite Member of the Drakes Formation (Ods) of Late Ordovician age and the Brassfield Dolomite (Formation) (Sb) of Early Silurian age. Minor relief of less than 6 in. common along unconformity. Roadcut on Kentucky Highway 1694 about 2.5 mi south of Skylight, Owen quadrangle, western north-central Kentucky.

CUMBERLAND RIVER REGION

The Cumberland River region of this report includes all the quadrangles in south-central Kentucky that contain outcrops of Ordovician rocks except for the Clementsville, Liberty, and Yosemite quadrangles in northernmost south-central Kentucky. The Ordovician formations that crop out in this region are, in ascending order: the Catheys(?) Formation, the Leipers Limestone, and the Cumberland Formation (fig. 2).

CATHEYS(?) FORMATION

The Catheys Formation was named by Hayes and Ulrich (1903, p. 2) for exposures along Catheys Creek in central Tennessee about 50 mi south of the Kentucky State line. Type sections were suggested by Bassler (1932, p. 106-107) and Wilson (1949, p. 137-138). The Catheys Formation as used by Wilson (1949, p. 136-157) in Tennessee is a partly faunally defined unit that ranges from 0 to more than 250 ft in thickness. The contact with the underlying "Bigby-Cannon limestone" of Wilson (1949) and the contact with the overlying Leipers Limestone are both inferred unconformities. Lithologically the Catheys Formation in Tennessee resembles the overlying Leipers Limestone. Dominant is dark-blue, in part muddy, fine-grained and medium- to coarse-grained limestone, containing abundant fossils and mostly in continuous wavy to nodular-surfaced beds, 3 to 24 in. thick, separated by partings and thin seams of gray shale.

The name "Catheys" is queried in Kentucky because poor and discontinuous exposures obscure the stratigraphic relations between the Kentucky unit and the Catheys Formation in its type area. Furthermore, the Catheys(?) Formation in Kentucky apparently differs lithologically from the Catheys as used by Wilson (1949) in Tennessee.

The Catheys(?) Formation in Kentucky crops out poorly along the Cumberland River in the Blacks Ferry quadrangle. The exposed part of the formation, about 80 ft thick, consists of gray partly muddy fine- to medium-grained limestone and dolomitic limestone and interbedded shale. The limestone is mostly in even to nodular beds, 2 to 24 in. thick, partly in thin sets and laminae and partly in lenses of crossbeds. Thin and medium sets of shale are interstratified irregularly with limestone. Fossils range from sparse to common and are chiefly abraded brachiopods and bryozoans. The upper contact is placed at the top of a zone of lithologic transition in which even-bedded limestone and dolomite of the Catheys(?) Formation grade upward to irregularly and nodular-bedded muddy medium- to coarse-grained limestone of the Leipers Limestone.

The stratigraphic relations of the Catheys(?) in Kentucky are poorly known. Examination of drill cores in the Dunnville quadrangle, northern south-central Kentucky, and in the Burkesville quadrangle, southern south-central Kentucky, suggests that the Catheys(?) of Kentucky is a southward extension of the Clays Ferry Formation, which it in part resembles. The Catheys(?) overlies rock lithologically allied to the Lexington Limestone of central Kentucky.

LEIPERS LIMESTONE

The Leipers Limestone was named by Hayes and Ulrich (1903) for exposures along Leipers Creek in southwestern central Tennessee, about 60 mi south of the Kentucky State line. The type section, suggested later by Bassler (1932, p. 116), is on Leipers Creek about 2 mi north of the town of Water Valley, central Tennessee.

Wilson (1949, p. 181-188) described three facies in the Leipers of Tennessee: (1) Argillaceous—dominantly bluish-gray muddy limestone in partly obscure thin nodular beds interlayered with partings and thin beds of gray calcitic shale; contains abundant fossils; (2) granular—dark-blue coarse-grained limestone, in part phosphatic, in thick beds, partly crossbedded, in places interlayered with lenses of gray calcitic shale containing abundant abraded fossils; and (3) pale-colored—dark-blue fine-grained limestone, in part muddy, fossiliferous.

In Kentucky, the argillaceous facies of Wilson (1949) makes up most of the Leipers; the granular facies is also present, chiefly in the lower part of the formation; and the pale-colored facies is absent. The general aspect of the Leipers Limestone of south-central Kentucky closely resembles that of the Grant Lake Limestone of north-central and northeast Kentucky. The Leipers exposed in Kentucky consists of limestone (70-90 percent) interbedded and intermixed with shale. The limestone is mostly bluish gray and gray, and is made up of poorly sorted whole to finely fragmented fossils in a somewhat muddy microcrystalline to finely crystalline matrix. The limestone is in irregularly wavy to nodular, thin to thick beds, interlayered with partings, thin beds, and lenses of bluish- to olive-gray calcitic shale. Fossils are abundant, chiefly brachiopods and bryozoans. About 10 to 20 percent of the limestone in the lower half of the Leipers of Kentucky is light- to medium-gray medium- to coarse-grained calcarenite, commonly in lenses, a few feet thick and probably several tens to a few hundreds of feet long, consisting of thin sets of low-angle crossbeds. The formation is generally poorly exposed and forms irregular gentle to moderate slopes interrupted by a few small ledges of calcarenite.

Outcrops of the Leipers Limestone in Kentucky are restricted to the valleys of the Cumberland River and its tributaries near the south border of the State (fig. 47). Generally only a few tens of feet are exposed. In the Blacks Ferry quadrangle, the only Kentucky quadrangle where the base of the formation has been mapped, the Leipers ranges in thickness from 120 to 180 ft. The Leipers Limestone is widespread in central Tennessee, where it ranges in thickness from 0 to about 250 ft (Wilson, 1949, fig. 54, p. 191).

In Tennessee, the contact between the Leipers Limestone and the underlying Catheys Formation is de-

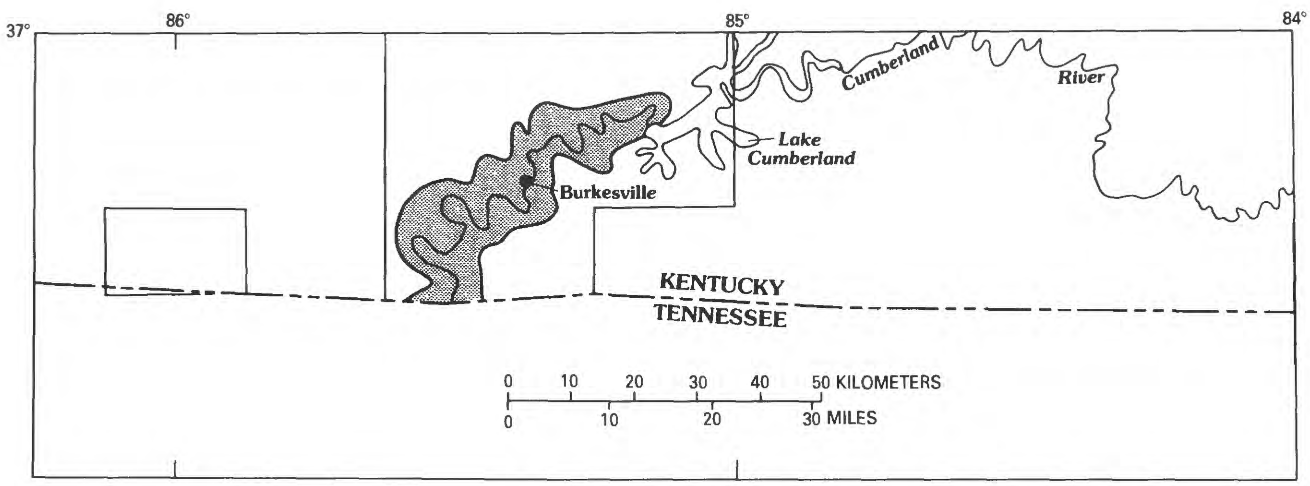

FIGURE 47.—Part of Kentucky, showing generalized area of outcrop (shaded) of the Leipers Limestone.

termined on the basis of a change in fossil fauna (Wilson, 1949, p. 190). In Kentucky, the contact is determined on the basis of a change in rock character, and so the Leipers as used in Kentucky may include more or fewer beds than the faunally defined Leipers of Tennessee. In the Blacks Ferry quadrangle, the contact was mapped at the top of a transition zone in which irregularly bedded muddy medium- to coarse-grained limestone of the Leipers grades downward to even-bedded limestone, dolomite, and shale assigned to the Catheys(?) Limestone as used by Jillson (1951b, p. 54).

Nodular muddy limestone of the Leipers is gradationally overlain by dolomite and dolomitic mudstone of the Cumberland Formation in Kentucky. The contact is placed so as to include most fossiliferous limestone in the Leipers. Beds in central and eastern Tennessee equivalent to the Cumberland were termed the "Sequatchie Formation" by Wilson (1949, p. 223), who inferred that its contact with the Leipers is an unconformity. In Kentucky, we have not recognized evidence of an unconformity at the top of the Leipers. Northward from the Cumberland River exposures, the Leipers Limestone apparently passes in the subsurface into the Calloway Creek Limestone of central and east-central Kentucky (pl. 7). The formations are separated by a cutoff, placed arbitrarily at the latitude of the south edge of the Hustonville quadrangle so as to restrict application of the name "Leipers Limestone" to the south-central part of the State.

CUMBERLAND FORMATION

The Cumberland [Sandstone] was named by Shaler (1877) for exposures of dolomitic strata at the top of the Ordovician section along the Cumberland River in Cumberland and adjacent counties, south-central Kentucky. The Cumberland, as used by Shaler (1877, p. 152, 153, 155, 159-160), was a broadly conceived unit that included not only the dolomitic rock in the Cumberland River drainage but also similar rock that crops out in the Blue Grass region of Kentucky and is now assigned to the Ashlock and Drakes Formations. Foerste (1900, 1901, 1902) used the name as it is used now by restricting it to the dolomitic outcrops along and near the Cumberland River in Kentucky. The misleading lithologic surname "sandstone" was dropped, and the unit designated a formation by Nelson (1962).

The Cumberland is composed chiefly of fine- to medium-grained dolomite. It is in part clayey and silty and rarely very fine sandy; it grades locally to dolomitic mudstone and siltstone. Dolomite and mudstone are in part calcitic and grade in places to micrograined limestone. Figure 5 plots the mineralogic composition of dolomite and mudstone of the Cumberland, calculated from analyses of some representative samples. Thin beds of light-gray chert occur locally in the lower part of the formation.

Most rocks of the Cumberland are light greenish gray to light gray, weather a fairly uniform grayish yellow, and are obscurely stratified in even laminae in sets a few inches to a few feet thick. Mud cracks, ripple marks, and trace fossils occur locally on bedding planes. Some thin layers in laminated dolomite underlying limestone contain rip-up clasts (fig. 48). The formation is moderately resistant and generally forms a series of ledges in an irregular steep slope or rounded to near-vertical cliffs.

The Cumberland is characteristically barren of megafossils, but near Burkesville, Ky., are two discontinuous zones of fossiliferous limestone. The lower zone, as much as 6 ft thick about 20 to 40 ft above the base of the formation, consists of thin lenses of micrograined limestone interbedded with minor calcitic mudstone. Brachiopods, bryozoans, and pelecypods are sparse to common; gastropods, ostracodes, and fragments of cephalopods and trilobites are rare. Jillson (1951a, p. 4) listed fossils that he identified from this zone. These fossiliferous limestone beds make up the Fowler Limestone of Foerste (1901) and the apparently synonymous Burkesville Limestone of Jillson (1951a). The stratigraphic position, lithology, and fossils of the Fowler Limestone of Foerste (1901) suggest that it is equivalent to the Gilbert or Reba Member of the Ashlock Formation of southern central Kentucky.

About 50 ft above the Fowler Limestone of Foerste (1901) is a discontinuous zone, as much as 7 ft thick, of thin beds of fossiliferous micrograined limestone inter-

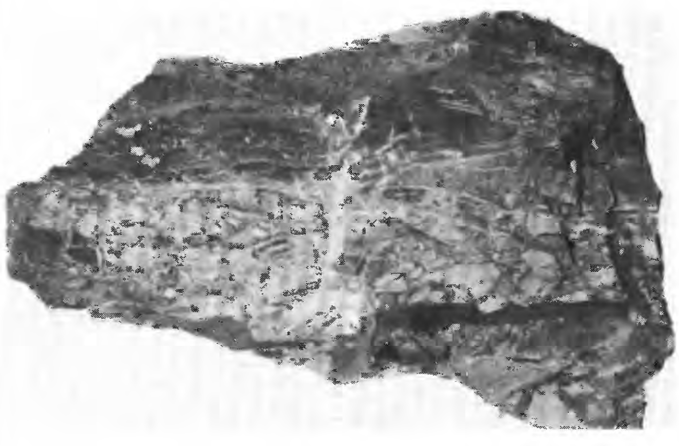

FIGURE 48.—Rip-up clasts of light-gray laminated dolomite in dark-gray dolomite of the Cumberland Formation, from bed immediately overlain by thin fossiliferous limestone that forms basal unit of Haggard Limestone of Jillson (1953). Block is 9 in. long. From outcrop along Kentucky Highway 90 about 1 mi west of Burkesville, Waterview quadrangle, south-central Kentucky.

calated with calcitic mudstone. Some beds of limestone in this zone contain abundant fragments of small brachiopods and bryozoans; some contain only trace fossils; sparse but most conspicuous are large colonial corals. A list of fossils from these beds was given by Jillson (1953, p. 12). This unit of fossiliferous limestone and mudstone constitutes the basal unit of the Haggard Limestone of Jillson (1953). The stratigraphic position, lithology, and fossils of the unit suggest that it is equivalent to fossiliferous beds at the base of the Preachersville Member of the Drakes Formation in southeastern central Kentucky and to the Bardstown Member of the Drakes Formation in southwestern central Kentucky.

The Cumberland Formation crops out in the southern part of south-central Kentucky and ranges in thickness from an erosional edge to about 130 ft (fig. 49). This large variation in thickness is the result of irregular truncation of the Cumberland by post-Ordovician erosion. The formation is unconformably overlain by strata of Silurian or Devonian age. Over most of its extent the Cumberland is overlain by the Chattanooga Shale of Middle and Late Devonian age. Locally in eastern south-central Kentucky, the superjacent formation is the Boyle Dolomite of Middle Devonian age; locally in western south-central Kentucky, it is the Brassfield Dolomite Formation of Early Silurian age (fig. 7) or the Osgood Formation of Middle Silurian age.

The Cumberland is separated on the north from laterally continuous lithologically similar rocks of the Ashlock and Drakes Formations by a vertical cutoff in the subsurface, arbitrarily placed at lat 37°15′ N., the south edge of the Liberty quadrangle, northern south-central Kentucky. The Ashlock and Drakes Formations of east-central and central Kentucky become more dolomitic and more alike southward. Thus, where strata equivalent to the Ashlock and Drakes are well exposed, as in the Dunnville quadrangle, northern south-central Kentucky, the two formations are inseparable and are here mapped as a single unit, the Cumberland Formation (pl. 7). Because the lithology of the Cumberland closely resembles that of the Saluda Dolomite Member of the Drakes Formation, earlier workers equated the Saluda with the Cumberland (Hudnall and Pirtle, 1924; Dunn and others, 1931). As suggested in plate 7, the Saluda probably passes into only the upper part of the Cumberland. Strata included in the Cumberland Formation in Kentucky occur in adjoining outcrops to the south in Tennessee that were equated by Wilson (1949, p. 219-223) with the Sequatchie Formation of east-central Tennessee.

The Cumberland Formation conformably overlies the Leipers Limestone; the lithology is commonly transitional through several feet. The contact is placed at the top of the transition zone so as to exclude fossiliferous limestone beds from the Cumberland.

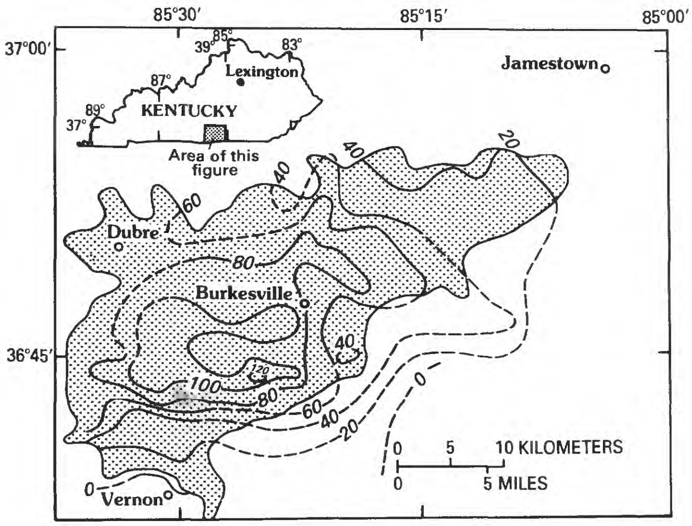

FIGURE 49.—Part of south-central Kentucky, showing generalized principal area of outcrop (shaded) and thickness of the Cumberland Formation. Contour interval, 20 ft; contours dashed where inferred.

FAUNA

Fossils were collected by the authors and the following members of the field-mapping team: D. F. B. Black, J. M. Cattermole, E. R. Cressman, A. B. Gibbons, R. C. Greene, R. C. Kepferle, R. Q. Lewis, Sr., S. J. Luft, W. H. Nelson, W. F. Outerbridge, J. H. Peck, F. A. Schilling, Jr., G. C. Simmons, and D. E. Wolcott. Fossil collections were also made by J. M. Berdan, O. L. Karklins, R. B. Neuman, W. A. Oliver, Jr., John Pojeta, Jr., R. J. Ross, Jr., and E. L. Yochelson. These collections in Kentucky are meant to be representative, not comprehensive; search was not made for rare forms, nor were all units sampled with equal spacing. The collections and relevant location data are in U.S. Geological Survey files at the U.S. National Museum, Washington, D.C., and Denver, Colo. A locality register for many of these collections was presented by Pojeta (1979, p. A19-A46).

The stratigraphic positions and ranges of many fossils collected during this study are shown in relation to the lithology of key sections in plates 1 through 5. Many small collections were previously reported in the texts of individual geologic quadrangle maps.

The bryozoans were identified by O. L. Karklins, the pelecypods by John Pojeta, Jr., the trilobites by R. J. Ross, Jr., the gastropods and monoplacophorans by E. L. Yochelson, the corals by W. A. Oliver, Jr., and the ostracodes by J. M. Berdan. The echinoderms were identified by B. M. Bell, formerly of the New York State Museum and Science Service; by J. W. Branstrator of Earlham College, Richmond, Ind.; and by R. L. Parsley of Tulane University, New Orleans, La. Brachiopods from collections prefixed with the letter "D" were identified by R. J. Ross, Jr., and those from all other collections by R. B. Neuman. These identifications were updated by L. P. Alberstadt of Vanderbilt University, Nashville, Tenn.; H. J. Howe of Purdue University, Lafayette, Ind.; J. K. Pope of Miami University, Oxford, Ohio; and L. G. Walker of the Hrubetz Oil Co. The paleontologists who made the identifications also posted the fossil names on plates 1 through 5 and checked the faunal lists presented below.

Studies of megafossils included in the collections from the Upper Ordovician section of Kentucky and nearby States include the reports by Neuman (1967), Ross (1967, 1979), Pojeta and Runnegar (1976, 1979), Alberstadt (1979), Bell (1979), Branstrator (1979), Howe (1979), and Pojeta (1979).

Conodonts listed in the collections were identified by Walter C. Sweet of Ohio State University, Columbus, Ohio. Information on the conodonts and analyses of the conodont biostratigraphy of the Upper Ordovician section of the Cincinnati arch region were reported by Bergström and Sweet (1966), Kohut (1968), Kohut and Sweet (1968), Sweet and Bergström (1976), and Sweet (1979).

The following tabulation, prepared by Marija Balanc and Robin Bell, lists the identified fossils by the stratigraphic unit in which they occur. The faunal list for each lithologic unit is arranged alphabetically by phylum.

Clays Ferry Formation:
- Arthropoda:
  - Ostracoda:
    - *Americoncha dubia* Warshauer and Berdan
    - *Anisocyamus*? sp.
    - *Ceratopsis asymmetrica* Warshauer and Berdan
      - *chambersi* (Miller)
      - *fimbriata* Warshauer and Berdan
      - *intermedia* (Ulrich)
    - *Ctenobolbina ventrispinifera* Warshauer and Berdan
    - *Laccoprimitia claysferryensis* Warshauer and Berdan
      - *cryptomorphologica* Warshauer and Berdan
      - *rudis* (Ulrich)
    - *Leperditella* sp. aff. *L. tumida* Ulrich
    - *Leperditella*? *perplexa* Warshauer and Berdan
    - *Parenthatia sadievillensis* Warshauer and Berdan
    - *Phelobythocypris cylindrica* (Hall)
    - *Pseudoprimitiella* sp.
    - *Quasibollia* aff. *Q. persulcata* (Ulrich)
      - *persulcata* (Ulrich)
    - *Schmidtella brevis* Ulrich
    - *Silenis kentuckyensis* Warshauer and Berdan
    - *Warthinia nodosa* (Ulrich)
  - Trilobita:
    - *Acidaspis* n. sp.
    - *Ceraurus* sp.

Clays Ferry Formation—Continued
- Arthropoda—Continued
  - Trilobita—Continued
    - *Flexicalymene meeki* (Foerste)
      - cf. *F. senaria* (Conrad)
      - sp.
    - *Flexicalymene*? sp.
    - *Isotelus gigas* deKay
      - sp.
    - *Isotelus*? sp.
    - *Metopolichas*? sp.
    - *Primaspis* cf. *P. evoluta* Törnquist
      - sp.
- Brachiopoda:
  - *Cyclospira* sp.
  - *Dalmanella bassleri* Foerste
    - *emacerata* (Hall)
    - *multisecta* Meek
    - sp.
  - Dalmanellid, indet.
  - *Dinorthis*? sp.
  - *Glyptorthis* sp.
  - *Hebertella frankfortensis* Foerste
    - *parksensis* Foerste
    - *occidentalis* (Hall)
    - sp.
  - *Pionodema* sp.
  - *Platystrophia* cf. *P. amoena* McEwan
    - *colbiensis* Foerste
    - ?*elegantula* McEwan
    - sp.
  - *Plectorthis trentonensis* Foerste
    - sp.
  - ?*Plectorthis* sp.
  - *Rafinesquina trentonensis* (Conrad)
    - *winchesterensis filistriata* Foerste
    - sp.
  - *Rhynchotrema* sp.
  - *Sowerbyella rugosa* (Meek)
    - cf. *S. rugosa* (Meek)
    - sp.
  - *Zygospira* aff. *Z. cincinnatiensis* Meek
    - cf. *Z. lebanonensis* Cooper
    - *modesta* Hall
    - cf. *Z. modesta* Hall
    - *recurvirostris* Hall
    - sp.
  - *Zygospira*? sp.
- Bryozoa:
  - *Amplexopora persimilis* Nickles
    - sp.
  - *Atactopora* sp.
  - *Atactoporella newportensis* Ulrich
    - sp.
  - *Bathostoma implicatum* (Nicholson)
  - *Bythopora*? sp.
  - *Ceramophylla alternatum* (James)
  - *Ceramophylla*? sp.
  - *Ceramoporella*? sp.
  - *Constellaria* cf. *C. fisheri* Ulrich
    - *teres* Ulrich and Bassler
  - *Dekayia*? sp.
  - *Eridotrypa* spp.
  - *Escharopora* sp.
  - *Graptodictya* sp.
  - *Hemiphragma* sp.
  - *Heterotrypa frondosa* (d'Orbigny)
    - *ulrichi* (Nicholson)

Clays Ferry Formation—Continued
Bryozoa—Continued
Heterotrypa spp.
Homotrypa sp.
Leptotrypa? sp.
Mesotrypa sp.
Parvohallopora nodulosa (Nicholson)
onealli (James)
Peronopora milleri Nickles
Stictopora sp.
Stigmatella clavis (Ulrich)
sp.
Coelenterata:
Anthozoa:
Tetradium sp.
Conodonta:
Amorphognathus superbus (Rhodes)
Aphelognathus politus (Hinde)
Belodina confluens Sweet
Drepanoistodus suberectus (Branson and Mehl)
Oulodus oregonia (Branson, Mehl and Branson)
Panderodus gracilis (Branson and Mehl)
Phragmodus undatus Branson and Mehl
Plectodina tenuis (Branson and Mehl)
Rhipidognathus symmetricus Branson, Mehl and Branson
Echinodermata:
Enoploura cf. *E. punctata* Bassler
Lanthanaster intermedius (Schuchert)
Promopalaeaster finei (Ulrich)
Graptolithina:
Climacograptus typicalis Hall
Mollusca:
Cephalopoda:
Orthonybyoceras sp.
Gastropoda and Monoplacophora:
Cyclonema bilex (Conrad)
cf. *C. varicosum* Hall
sp.
?*Cyclonema* sp.
Cyrtolites retrorsus Ulrich in Ulrich and Scofield
sp.
?*Cyrtolites* sp.
Liospira progne (Billings)
cf. *L. progne* (Billings)
sp.
?*Liospira* sp.
Loxoplocus (*Lophospira*) *abnormis* (Ulrich in Ulrich and Scofield)
cf. *L.* (*L.*) *burginensis* (Ulrich in Ulrich and Scofield)
medialis (Ulrich in Ulrich and Scofield)
sp.
?*Loxoplocus* (*Lophospira*) sp.
?*Murchisonia* (*Hormotoma*) sp.
Sinuites sp.
Sphenosphaera clausus (Ulrich in Ulrich and Scofield)
sp.
Tropidodiscus sp.
?*Tropidodiscus* sp.
Pelecypoda:
Ambonychia byrnesi (Ulrich)
radiata Hall
Caritodens sp.
Colpomya faba (Emmons)
sp.
Ctenodonta aff. *C. iphigenia* Billings
sp.

Clays Ferry Formation—Continued
Mollusca—Continued
Pelecypoda—Continued
"*Ctenodonta*" aff. "*C.*" *longa* (Ulrich)
pulchella (Ulrich)
Cycloconcha ovata Ulrich
sp.
Deceptrix cf. *D. filistriata* (Ulrich)
cf. *D. perminuta* (Ulrich)
sp.
Lyrodesma subplanum Ulrich
sp.
Modiolopsis aff. *M. simulatrix* Ulrich
sp.
Paleopteria sp.
?*Physetomya* sp.
Whiteavesia cincinnatiensis (Hall and Whitfield)
pulchella Ulrich
Whiteavesia? sp.
Point Pleasant Tongue:
Brachiopoda:
Dalmanella bassleri Foerste
sp.
Hebertella frankfortensis Foerste
Plectorthis trentonensis Foerste
Rafinesquina trentonensis (Conrad)
sp.
Sowerbyella sp.
Zygospira sp.
Bryozoa:
Atactoporella sp.
Eridotrypa spp.
Heterotrypa sp.
Mesotrypa sp.
Parvohallopora onealli (James)
Peronopora spp.
Echinodermata:
Carnyella pilea (Hall)
Cystaster stellatus (Hall)
Mollusca:
Gastropoda:
Cyclonema cf. *C. varicosum* Hall
sp. indet.
Moderately high spired gastropod, indet.
Pelecypoda:
Ambonychia byrnesi (Ulrich)
radiata (Hall)
"*Ctenodonta*" aff. "*C.*" *longa* (Ulrich)
Cycloconcha ovata Ulrich
cf. *C. ovata* Ulrich
Deceptrix cf. *D. filistriata* Ulrich
sp.
Lyrodesma subplanum Ulrich
cf. *L. subplanum* Ulrich
Modiolopsis aff. *M. simulatrix* Ulrich
Whiteavesia cincinnatiensis (Hall and Whitfield)
cf. *W. cincinnatiensis* (Hall and Whitfield)
Kope Formation:
Arthropoda:
Trilobita:
Flexicalymene sp.
Brachiopoda:
Dalmanella emacerata (Hall)
multisecta (Meek)
sp.
?*Glyptorthis* sp.

Kope Formation—Continued
- Brachiopoda—Continued
  - ?*Hebertella* sp.
  - *Holtedahlina* sp.
  - *Rafinesquina* sp.
  - *Sowerbyella* sp.
  - ?*Sowerbyella* sp.
  - *Zygospira modesta* Hall
    - sp.
- Bryozoa:
  - *Amplexopora persimilis* Nickles
  - *Bythopora* sp.
  - *Constellaria* sp.
  - *Cyphotrypa* sp.
  - *Eridotrypa* sp.
  - *Escharopora* sp.
  - *Graptodictya* sp.
  - *Heterotrypa ulrichi* (Nicholson)
    - sp.
  - *Homotrypa* sp.
  - *Mesotrypa* sp.
  - *Mesotrypa*? sp.
  - *Parvohallopora onealli* (James)
  - *Peronopora* sp.
  - *Phylloporina* sp.
  - *Stigmatella*? sp.
- Conodonta:
  - *Aphelognathus politus* (Hinde)
  - *Drepanoistodus suberectus* (Branson and Mehl)
  - *Oulodus oregonia* (Branson, Mehl and Branson)
  - *Panderodus gracilis* (Branson and Mehl)
  - *Phragmodus undatus* (Branson and Mehl)
  - *Plectodina tenuis* (Branson and Mehl)
  - *Staufferella falcata* (Stauffer)
- Echinodermata:
  - *Lanthanaster intermedius* (Schuchert)
  - *Promopalaeaster finei* (Ulrich)
- Graptolithina:
  - *Climacograptus typicalus* Hall
- Mollusca:
  - Pelecypoda:
    - *Ambonychia radiata* Hall
    - *Deceptrix perminuta* (Ulrich)
    - *Lyrodesma* sp.
    - *Modiolopsis* aff. *M. simulatrix* Ulrich
    - *Similodonta obliqua* (Hall)
    - *Whiteavesia*? sp.

Garrard Siltstone:
- Arthropoda:
  - Trilobita:
    - *Isotelus*? sp.
- Brachiopoda:
  - *Rafinesquina* sp.
  - *Zygospira* sp.
- Bryozoa:
  - *Calloporella*? sp.
  - *Constellaria* cf. *C. teres* Ulrich and Bassler
  - *Heterotrypa frondosa* (d'Orbigny)
    - sp.
  - *Parvohallopora nodulosa* (Nicholson)
  - *Stigmatella clavis* (Ulrich)
    - sp.
- Conodonta:
  - *Aphelognathus politus* (Hinde)
  - *Drepanoistodus suberectus* (Branson and Mehl)

Garrard Siltstone—Continued
- Conodonta—Continued
  - *Oulodus oregonia* (Branson, Mehl and Branson)
  - *Phragmodus undatus* Branson and Mehl
  - *Plectodina tenuis* (Branson and Mehl)

Fairview Formation:
- Brachiopoda:
  - *Austinella*? sp.
  - *Dalmanella* sp.
  - *Dalmanella*? sp.
  - *Dinorthis*? sp.
  - ?*Dinorthis* sp.
  - *Hebertella occidentalis* (Hall)
    - sp.
  - ?*Holtedahlina* sp.
  - *Megamyonia*? sp.
  - *Platystrophia ponderosa* Foerste
    - *profundosulcata* (Meek)
    - sp.
  - *Plectorthis* sp.
  - *Plectorthis*? sp.
  - *Rafinesquina nasuta* (Conrad)
    - sp.
  - *Strophomena maysvillensis* Foerste
    - cf. *S. maysvillensis* Foerste
    - cf. *S. planoconvexa* Hall
    - sp.
  - *Zygospira modesta* Hall
    - cf. *Z. modesta* Hall
    - sp.
- Bryozoa:
  - *Amplexopora septosa* (Ulrich)
    - sp.
  - *Atactoporella mundula* (Ulrich)
  - *Batostoma implicatum* (Nicholson)?
    - spp.
  - *Batostomella* spp.
  - *Constellaria* spp.
  - *Escharopora* sp.
  - *Graptodictya* sp.
  - *Heterotrypa ulrichi* (Nicholson)
    - sp.
  - *Homotrypa* cf. *H. spinea* Cummings and Galloway
    - spp.
  - *Monticulipora* spp.
  - *Parvohallopora* sp.
  - *Peronopora* sp.
  - *Peronopora*? sp.
  - *Stictopora* sp.
- Conodonta:
  - *Aphelognathus politus* (Hinde)
  - *Drepanoistodus suberectus* (Branson and Mehl)
  - *Oulodus oregonia* (Branson, Mehl and Branson)
  - *Phragmodus undatus* Branson and Mehl
  - *Plectodina tenuis* (Branson and Mehl)
  - *Rhipidognathus symmetricus* Branson, Mehl and Branson
  - *Staufferella falcata* (Stauffer)
- Mollusca:
  - Pelecypoda:
    - *Ambonychia byrnesi* (Ulrich)
      - cf. *A. byrnesi* (Ulrich)
      - sp.
- Miamitown Shale Member:
  - Brachiopoda:
    - *Hebertella* sp.

Calloway Creek Limestone:
- Arthropoda:
  - Ostracoda:
    - *Cryptophyllus* sp.
    - *Krausella* sp.
    - *Laccoprimitia* sp.
    - *Leperditella*? sp.
    - *Quasibollia persulcata* (Ulrich)
    - Smooth ostracodes, indet.
    - *Warthinia* aff. *W. nodosa* (Ulrich)
      - sp.
  - Trilobita:
    - *Flexicalymene*? sp.
- Brachiopoda:
  - *Dalmanella* sp.
  - Dalmanellid
  - *Hebertella occidentalis* (Hall)
    - sp.
  - *Orthorhyncula linneyi* (James)
  - *Platystrophia ponderosa* Foerste
    - cf. *P. ponderosa* Foerste
    - cf. *P. hopensis* Foerste
    - cf. *P. laticosta* (Meek)
    - sp.
  - *Rafinesquina* aff. *R. fracta* (Meek)
    - cf. *R. alternata* (Emmons)
    - cf. *R. fracta* (Meek)
    - cf. *R. ponderosa* Hall
    - sp.
  - *Strophomena maysvillensis* Foerste
    - cf. *S. maysvillensis* Foerste
    - *planoconvexa* Hall
    - cf. *S. planoconvexa* Hall
    - sp.
  - *Zygospira cincinnatiensis* Meek
    - *modesta* Hall
    - cf. *Z. recurvirostris* Hall
    - sp.
- Bryozoa:
  - *Amplexopora ampla* Ulrich and Bassler
    - cf. *A. septosa* (Ulrich)
    - spp.
  - *Batostoma implicatum* (Nicholson)
    - spp.
  - *Bythopora dendrina* (James)
  - *Ceramoporella* sp.
  - *Ceramoporella*? sp.
  - *Constellaria florida* Ulrich
    - spp.
  - *Crepipora simulans* Ulrich
  - *Dekayia* cf. *D. appressa* Ulrich
    - *aspera* Milne-Edwards and Haime
    - cf. *D. nicklesi* (Ulrich and Bassler)
    - spp.
  - *Escharopora falciformis* (Nicholson)
    - *hilli* (James)
    - cf. *E. hilli* (James)
    - sp.
  - *Parvohallopora* cf. *P. ramosa* (d'Orbigny)
    - spp.
  - *Heterotrypa* cf. *H. frondosa* (d'Orbigny)
    - sp.
  - *Homotrypa* cf. *H. flabellaris spinifera* Bassler
    - spp.
  - *Homotrypa*? sp.
  - Heterotrypid, indet.

Calloway Creek Limestone—Continued
- Bryozoa—Continued
  - *Monticulipora* sp.
  - *Parvohallopora ramosa* (d'Orbigny)
  - *Peronopora* cf. *P. decipiens* (Rominger)
    - sp.
  - *Phylloporina* sp.
  - *Phylloporina*? sp.
  - *Stictopora* sp.
- Echinodermata:
  - *Cyclocystoides*
- Graptolithina:
  - *Climacograptus typicalus* Hall
- Mollusca:
  - Cephalopoda:
    - *Beloitoceras* sp.
    - *Orthonybyoceras* sp.
  - Gastropoda:
    - *Cyclonema bilex bilex* (Conrad)
      - cf. *C. medialis* Ulrich in Ulrich and Scofield
      - sp. indet.
    - *Loxoplocus* sp.?
    - Murchisoniid gastropod
  - Pelecypoda:
    - *Ambonychia* spp.
    - *"Ctenodonta"* cf. *"C." pectunculoides* (Hall)

Grant Lake Limestone:
- Arthropoda:
  - Ostracoda:
    - *Bolbopisthia* sp. aff. *B. reticulata* (Kirk)
    - *Ceratopsis oculifera* (Hall)
      - sp. aff. *C. oculifera* (Hall)
      - sp.
    - *Cryptophyllus* sp.
    - *Ctenobolbina* aff. *C. ciliata* (Emmons)
      - sp.
    - *Ctenobolbina*? sp.
    - *Kenodontochilina* aff. *K. subnodosa glabra* Berdan
    - *Laccoprimitia* sp.
    - *Leperditella* sp.
    - *Leperditella*? sp.
    - *Quasibollia persulcata* (Ulrich)
    - *Saffordellina striatella* Berdan
    - Smooth ostracodes, indet.
    - *Warthinia nodosa* (Ulrich)
      - sp. aff. *W. nodosa* (Ulrich)
      - sp.
- Brachiopoda:
  - *Hebertella occidentalis* (Hall)
    - spp.
  - *Platystrophia cypha* (James)
    - *laticosta* (Meek)
    - cf. *P. laticosta* (Meek)
    - *ponderosa* Foerste
    - cf. *P. ponderosa* Foerste
  - *Rafinesquina* cf. *R. alternata* (Emmons)
    - sp.
  - *Strophomena* sp.
  - *Zygospira modesta* Hall
    - aff. *Z. modesta* Hall
    - cf. *Z. modesta* Hall
    - sp.
- Bryozoa:
  - *Amplexopora ampla* Ulrich and Bassler
    - cf. *A. filiasa* (d'Orbigny)
    - spp.

Grant Lake Limestone—Continued
  Bryozoa—Continued
    Atactoporella mundula (Ulrich)
      sp.
    Atactoporella? sp.
    Batostoma implicatum (Nicholson)?
      spp.
    Batostomella gracilis (Nicholson)
      spp.
    Bythopora dendrina (James)
      aff. *B. dendrina* (James)
      sp.
    Calloporella sp.
    Ceramoporella sp.
    Ceramoporella? sp.
    Constellaria florida Ulrich
      spp.
    Crepipora? sp.
    Cyphotrypa? sp.
    Dekayia cf. *D. appressa* Ulrich
      aspera Milne-Edwards and Haime
      cf. *D. nicklesi* (Ulrich and Bassler)
      spp.
    Dekayia? sp.
    Graptodictya sp.
    Heterotrypa frondosa (d'Orbigny)
      inflecta Ulrich
      sp.
    Homotrypa cf. *H. flabellaris spinifera* Bassler
      cf. *H. pulchra* Bassler
      cf. *H. spinea* Cummings and Galloway
      spp.
    Homotrypa? sp.
    Mesotrypa? sp.
    Monticulipora spp.
    Nicholsonella? sp.
    Parvohallopora ramosa (d'Orbigny)
    Peronopora cf. *P. decipiens* (Rominger)
      spp.
    Rhabdosomids, undet.
    Stictopora cf. *S. lata* (Ulrich)
    Stictoporid, undet.
    Stigmatella? sp.
    Trigonodictya? sp.
  Conodonta:
    Aphelognathus grandis Branson and Mehl
    Drepanoistodus suberectus (Branson and Mehl)
    Oulodus oregonia (Branson, Mehl and Branson)
    Phragmodus undatus Branson and Mehl
    Plectodina tenuis (Branson and Mehl)
    Rhipidognathus symmetricus Branson, Mehl and Branson
  Echinodermata:
    Cyclocystoides
  Mollusca:
    Gastropoda:
      Cyclonema sp. indet.
      Loxoplocus (?*Donaldiella*) sp. indet.
    Pelecypoda:
      Ambonychia sp.
      Caritodens demissa (Conrad)
      "Ctenodonta" cingulata Ulrich
        aff. *C. iphigenia* Billings
        aff. *"C." longa* (Ulrich)
        pectunculoides (Hall)
      Deceptrix cf. *D. filistriata* (Ulrich)
      Deceptrix? sp.

Grant Lake Limestone—Continued
  Mollusca—Continued
    Pelecypoda—Continued
      Ischyrodonta sp.
      Lyrodesma sp. indet.
      Modiolodon? sp.
  Stromatoporoidea:
    Stromatocerium sp.
Ashlock Formation:
  Arthropoda:
    Ostracoda:
      Bolbopisthia cf. *B. reticulata* (Kirk)
        sp.
      Ctenobolbina sp. aff. *C. ciliata* (Emmons)
      Isochilina copelandi Berdan
      Kenodontochilina pustulosa Berdan
        subnodosa glabra Berdan
      Laccoprimitia sp.
      Platybolbina? sp.
      Smooth ostracodes, indet.
    Trilobita:
      Isotelus sp.
  Brachiopoda:
    Hebertella occidentalis (Hall)
      sp.
    Leptaena richmondensis Foerste
      kentuckiana Pope
    Plaesiomys sp.
    Platystrophia cypha (James)
      juvensis McEwan
      laticosta (Meek)
      cf. *P. laticosta* (Meek)
      ponderosa Foerste
      cf. *P. ponderosa* Foerste
      sp.
    Rafinesquina cf. *R. alternata* (Emmons)
      spp.
    Rhynchotrema dentatum (Hall)
      sp.
    Strophomena sp.
    Zygospira modesta Hall
      aff. *Z. modesta* Hall
      cf. *Z. modesta* Hall
      sp.
  Bryozoa:
    Amplexopora cf. *A. robusta* Ulrich
      sp.
    Constellaria sp.
    Heterotrypa sp.
    Homotrypa sp.
    Parvohallopora sp.
    Peronopora cf. *P. decipiens* (Rominger)
    Stigmatella sp.
  Conodonta:
    Aphelognathus grandis Branson and Mehl
    Drepanoistodus suberectus (Branson and Mehl)
    Plectodina tenuis (Branson and Mehl)
    Rhipidognathus symmetricus Branson, Mehl and Branson
  Echinodermata:
    Cyclocystoides
  Mollusca:
    Gastropoda and Monoplacophora:
      Bellerophontacean, indet., cf. *Salpingostoma* sp.
      ?*Bucania* cf. ?*B. crassa* (Ulrich in Ulrich and Scofield)
        sp. indet.
      Cyclonema frag.

Ashlock Formation—Continued
- Mollusca—Continued
  - Gastropoda and Monoplacophora—Continued
    - ?*C. simulans* Ulrich in Ulrich and Scofield
    - *Cyrtolites* sp.
    - *Loxoplocus* (*Donaldiella*) *bowdeni* (Safford)
      - aff. *L.* (*D.*) *bowdeni* (Safford)
      - sp. indet.
    - *Loxoplocus* (*Lophospira*) cf. *L.* (*L.*) *ampla* (Ulrich in Ulrich and Scofield)
      - aff. *L.* (*L.*) *quadrisulcata* (Ulrich in Ulrich and Scofield)
      - sp. indet.
      - sp. indet. but of *L.* (*L.*) *milleri* group
    - "*Murchisonia*" sp. indet.
    - ?*Tropidodiscus* sp. indet.
  - Pelecypoda:
    - *Ambonychia alata* Meek
      - cf. *A. praecursa* (Ulrich)
      - sp.
    - *Caritodens demissa* (Conrad)
      - cf. *C. demissa* (Conrad)
    - "*Ctenodonta*" *cingulata* Ulrich
      - aff. *C. iphigenia* Billings
    - *Deceptrix* cf. *D. filistriata* (Ulrich)
    - *Ischyrodonta*? sp.
    - Modiolopsid
    - *Opisthoptera* sp. indet.
  - Stromatoporoidea:
    - *Stromatocerium* sp.
- Tate Member:
  - Arthropoda:
    - Trilobita:
      - *Isotelus* sp.
  - Brachiopoda:
    - *Hebertella occidentalis* (Hall)
      - sp.
    - *Platystrophia ponderosa* Foerste
      - cf. *P. ponderosa* Foerste
      - sp.
    - *Zygospira* sp.
  - Bryozoa:
    - *Amplexopora* cf. *A. robusta* Ulrich
      - sp.
    - *Constellaria* sp.
    - *Heterotrypa* sp.
    - *Homotrypa* sp.
    - *Parvohallopora* sp.
    - *Peronopora* cf. *P. decipiens* (Rominger)
    - *Stigmatella* sp.
  - Conodonta:
    - *Aphelognathus grandis* Branson and Mehl
    - *Drepanoistodus suberectus* (Branson and Mehl)
    - *Plectodina tenuis* (Branson and Mehl)
    - *Rhipidognathus symmetricus* Branson, Mehl and Branson
  - Mollusca:
    - Gastropoda:
      - *Loxoplocus* (*Lophospira*) sp. indet. but of *L.* (*L.*) *milleri* group
      - "*Murchisonia*" sp. indet.
    - Pelecypoda:
      - Ambonychiids
      - *Caritodens* cf. *C. demissa* (Conrad)
      - Modiolopsid
  - Back Bed:
    - Brachiopoda:
      - *Hebertella occidentalis* (Hall)

Ashlock Formation—Continued
- Tate Member—Continued
  - Back Bed—Continued
    - Brachiopoda—Continued
      - *Platystrophia ponderosa* Foerste
    - Echinodermata:
      - *Cyclocystoides*
    - Mollusca:
      - Pelecypoda:
        - *Ambonychiids*
        - *Caritodens* cf. *C. demissa* (Conrad)
        - Modiolopsid
- Gilbert Member:
  - Arthropoda:
    - Ostracoda:
      - *Bolbopisthia* sp. cf. *B. reticulata* (Kirk)
      - *Ctenobolbina* sp. aff. *C. ciliata* (Emmons)
      - *Kenodontochilina subnodosa glabra* Berdan
      - *Laccoprimitia* sp.
      - *Saffordellina striatella* Berdan
  - Brachiopoda:
    - *Hebertella occidentalis* (Hall)
      - sp.
    - *Leptaena richmondensis* Foerste
    - *Platystrophia cypha* (James)
      - *juvensis* McEwan
      - *ponderosa* Foerste
      - sp.
    - *Rhynchotrema* sp.
    - *Zygospira* sp.
  - Conodonta:
    - *Aphelognathus grandis* Branson and Mehl
    - *Rhipidognathus symmetricus* Branson, Mehl and Branson
  - Echinodermata:
    - *Cyclocystoides*
  - Mollusca:
    - Gastropoda and Monoplacophora:
      - Bellerophontacean, indet., cf. *Salpingostoma* sp.
      - ?*Bucania* cf. ?*B. crassa* (Ulrich in Ulrich and Scofield)
      - ?*Bucania* sp. indet.
      - *Cyrtolites* sp.
      - *Loxoplocus* (*Donaldiella*) *bowdeni* (Safford)
        - aff. *L.* (*D.*) *bowdeni* (Safford)
        - sp. indet.
      - *Loxoplocus* (*Lophospira*) cf. *L.* (*L.*) *ampla* (Ulrich in Ulrich and Scofield)
        - aff. *L.* (*L.*) *quadrisulcata* (Ulrich in Ulrich and Scofield
        - spp. indet.
      - ?*Tropidodiscus sp. indet.*
    - Pelecypoda:
      - *Ambonychia* cf. *A. praecursa* (Ulrich)
        - sp.
      - *Caritodens demissa* (Conrad)
        - cf. *C. demissa* (Conrad)
      - *Ctenodonta* aff. *C. iphigenia* Billings
      - "*Ctenodonta*" *cingulata* Ulrich
      - *Deceptrix* cf. *D. filistriata* (Ulrich)
      - *Ischyrodonta*? sp.
- Stingy Creek Member:
  - Brachiopoda:
    - *Hebertella* sp.
    - *Leptaena richmondensis* Foerste
    - *Platystrophia cypha* (James)
      - *ponderosa* Foerste
    - *Zygospira* sp.

Ashlock Formation—Continued
- Sunset Member:
  - Arthropoda:
    - Ostracoda:
      - *Bolbopisthia* cf. *B. reticulata* (Kirk)
        - aff. *B. reticulata* (Kirk)
        - sp.
      - *Ceratopsis* sp.
      - *Chilobolbina*? sp.
      - *Isochilina copelandi* Berdan
      - *Kenodontochilina pustulosa* Berdan
        - *subnodosa glabra* Berdan
      - *Laccoprimitia* sp.
      - *Leperditella* sp.
      - *Platybolbina*? sp.
      - *Saffordellina striatella* Berdan
      - *Shenandoia* sp.
      - Smooth ostracodes, indet.
  - Brachiopoda:
    - *Zygospira* sp.
  - Bryozoa:
    - *Amplexopora robusta* Ulrich
      - sp.
    - *Graptodictya* sp.
    - Monticuliporids, undet.
- Reba Member:
  - Brachiopoda:
    - *Hebertella occidentalis* (Hall)
      - sp.
    - *Leptaena kentuckiana* Pope
    - *Platystrophia cypha* (James)
      - *ponderosa* Foerste
      - sp.
    - *Rhynchotrema dentatum* (Hall)
    - *Rafinesquina* sp.
    - *Zygospira* sp.
  - Bryozoa:
    - *Amplexopora* sp.
  - Conodonta:
    - *Aphelognathus grandis* Branson and Mehl
    - *Drepanoistodus suberectus* (Branson and Mehl)
    - *Plectodina tenuis* (Branson and Mehl)
    - *Rhipidognathus symmetrica* (Branson, Mehl and Branson)
  - Mollusca:
    - Gastropoda:
      - *Cyclonema* sp. frag.
      - ?*C. simulans* Ulrich in Ulrich and Scofield
    - Pelecypoda:
      - *Ambonychia alata* Meek
      - *Opisthoptera* sp. indet.

Bull Fork Formation:
- Arthropoda:
  - Ostracoda:
    - *Aechmina richmondensis* Ulrich and Bassler
    - *Bolbopisthia* aff. *B. reticulata* (Kirk)
      - cf. *B. reticulata* (Kirk)
      - sp.
    - *Ceratopsis* sp.
    - *Chilobolbina*? sp.
    - *Craspedopyxion*? sp.
    - *Ctenobolbina* sp.
    - *Ctenobolbina*? sp.
    - *Eridoconcha*? sp.
    - *Isochilina* sp.
    - *Kenodontochilina pustulosa* Berdan
      - *subnodosa glabra* Berdan

Bull Fork Formation—Continued
- Arthropoda—Continued
  - Ostracoda—Continued
    - *Krausella* sp.
    - *Laccoprimitia* cf. *L. shideleri* (Levinson)
      - sp.
    - *Leperditella* sp.
    - *Leperditella*? sp.
    - *Milleratia cincinnatiensis* (Miller)
      - cf. *M. cincinnatiensis* (Miller)
      - sp.
    - *Milleratia*? sp.
    - *Monotiopleura auriculata* Guber and Jaanusson
    - *Platybolbina*? sp.
    - *Quasibollia persulcata* (Ulrich)
      - cf. *Q. ridicula* (Keenan)
    - *Saffordellina striatella* Berdan
    - *Shenandoia* sp.
    - *Schmidtella* sp.
    - Smooth ostracodes, indet.
    - *Tetradella scotti* Guber
      - sp.
    - *Warthinia nodosa* (Ulrich)
      - *saccula* (Burr and Swain)
      - aff. *W. saccula* (Burr and Swain)
      - sp.
  - Trilobita:
    - Calymenid
    - *Flexicalymene meeki* (Foerste)
      - sp.
    - *Flexicalymene*? sp.
- Brachiopoda:
  - *Catazyga headi* (Billings)
  - *Dalmanella meeki* (Miller)
    - cf. *D. meeki* (Miller)
    - sp.
  - Dalmanellid
  - *Hebertella occidentalis* (Hall)
    - sp.
  - *Hebertella*? sp.
  - *Holtedahlina sulcata* (de Verneuil)
  - *Holtedahlina*? sp.
  - *Lepidocyclus*? *capax* (Conrad)
  - *Leptaena richmondensis* Foerste
    - sp.
  - Lingullelid
  - *Plaesiomys subquadrata* (Hall)
    - cf. *P. subquadrata* (Hall)
    - sp.
  - *Platystrophia acutilirata* (Conrad)
    - *clarksvillensis* Foerste
    - cf. *P. clarksvillensis* Foerste
    - *cypha* (James)
    - cf. *P. cypha* (James)
    - *laticosta* (Meek)
    - *ponderosa* Foerste
    - cf. *P. ponderosa* Foerste
    - cf. *P. foerstei* McEwan
    - cf. *P. laticosta* (Meek)
    - sp.
  - *Plectorthis triplicatella* (Meek)
  - *Plectorthis*? sp.
  - *Rafinesquina alternata* (Emmons)
    - cf. *R. alternata* (Emmons)
    - *loxorhytis* (Meek)
    - cf. *R. loxorhytis* (Meek)
    - sp.

Bull Fork Formation—Continued
- Brachiopoda—Continued
  - *Rafinesquina*? sp.
  - *Retrorsirostra carleyi* (Hall)
  - *Rhynchotrema dentatum* (Hall)
  - *Strophomena nutans* Meek
    - cf. *S. planoconvexa* Hall
    - *planumbona* Hall
    - cf. *S. planumbona* Hall
    - *vetusta* (James)
    - sp.
  - *Thaerodonta clarksvillensis* (Foerste)
    - sp.
  - *Thaerodonta*? cf. *T. clarksvillensis* (Foerste)
  - *Zygospira modesta* Hall
    - cf. *Z. modesta* Hall
    - sp.
- Bryozoa:
  - *Amplexopora ampla* Ulrich and Bassler
    - cf. *A. pustulosa* Ulrich
    - *robusta* Ulrich
    - spp.
  - *Batostoma* spp.
  - *Batostomella gracilis* (Nicholson)
    - cf. *B. meeki* (James)
    - spp.
  - *Bythopora dendrina* (James)
    - aff. *B. dendrina* (James)
    - sp.
  - *Ceramoporella* cf. *C. ohioensis* (Nicholson)
    - sp.
  - *Constellaria* sp.
  - *Crepipora* sp.
  - *Cyphotrypa*? sp.
  - *Dekayia* cf. *D. appressa* Ulrich
    - *aspera* Milne-Edwards and Haime
    - cf. *D. aspera* Milne-Edwards and Haime
    - cf. *D. nicklesi* (Ulrich and Bassler)
    - spp.
  - *Dekayia*? sp.
  - *Eridotrypa* sp.
  - *Escharopora* sp.
  - *Gortanipora bassleri* (Nickles)
    - cf. *G. bassleri* (Nickles)
    - cf. *G. richmondensis* (Bassler)
    - sp.
  - *Graptodictya* sp.
  - *Heterotrypa* cf. *H. frondosa* (d'Orbigny)
    - spp.
  - *Homotrypa* cf. *H. cincinnatiensis* Bassler
    - cf. *H. pulchra* Bassler
    - sp.
  - *Homotrypa*? sp.
  - *Monticulipora* sp.
  - Monticuliporids, undet.
  - *Nicholsonella*? sp.
  - *Parvohallopora ramosa* (d'Orbigny)
  - *Peronopora* cf. *P. decipiens* (Rominger)
    - sp.
  - *Phylloporina*? sp.
  - Rhabdosomids, undet.
  - *Rhombotrypa quadrata* (Rominger)
    - cf. *R. quadrata* (Rominger)
  - *Stictopora* cf. *S. lata* (Ulrich)
  - *Stigmatella crenulata* Ulrich and Bassler
    - sp.
  - *Stigmatella*? sp.

Bull Fork Formation—Continued
- Bryozoa—Continued
  - Stigmatellids, undet.
  - *Trigonodictya*? sp.
- Coelenterata:
  - Anthozoa:
    - *Calapoecia huronensis* Billings
    - *Favistina stellata* (Hall)
    - *Foerstephyllum vacuum* (Foerste)
    - *Grewingkia canadensis* (Billings)
    - "*Streptelasma*" spp.
    - *Tetradium approximatum* Bassler
- Conodonta:
  - *Aphelognathus grandis* Branson and Mehl
  - *Drepanoistodus suberectus* (Branson and Mehl)
  - *Oulodus oregonia* (Branson, Mehl and Branson)
  - *Panderodus* spp.
  - *Phragmodus undatus* Branson and Mehl
  - *Plectodina tenuis* (Branson and Mehl)
  - *Rhipidognathus symmetricus* Branson, Mehl and Branson
- Mollusca:
  - Gastropoda:
    - *Cyclonema humerosum* Ulrich in Ulrich and Scofield
      - cf. *C. humerosum* Ulrich in Ulrich and Scofield
      - sp. indet.
  - Pelecypoda:
    - *Ambonychia alata* Meek
      - sp.
    - *Caritodens demissa* (Conrad)
      - cf. *C. demissa* (Conrad)
    - *Deceptrix*? sp.
    - *Modiolodon*? sp.
- Stromatoporoidea:
  - *Stromatocerium* sp.

Drakes Formation:
- Arthropoda:
  - Ostracoda:
    - *Coelochilina*? sp.
    - *Ctenobolbina* sp.
    - *Eridoconcha* sp.
    - *Glymmatobolbina*? sp.
    - *Isochilina* sp.
    - *Krausella* sp.
    - *Laccoprimitia* sp.
    - *Leperditella* sp.
    - *Milleratia cincinnatiensis* (Miller)
    - *Monotiopleura* sp.
    - ?*Platybolbina* (*Rimabolbina*) sp.
    - *Pseudotallinella*? sp.
    - *Schmidtella*? sp.
    - Smooth ostracodes, indet.
- Brachiopoda:
  - *Hebertella occidentalis* (Hall)
    - sp.
  - *Lepidocyclus*? *capax* (Conrad)
  - *Plaesiomys subquadrata* (Hall)
  - *Platystrophia annieana* McEwan
    - *attenuata* McEwan
    - *foerstei* McEwan
    - *ponderosa* Foerste
    - cf. *P. clarksvillensis* Foerste
    - cf. *P. cypha* (James)
    - sp.
  - *Rafinesquina* sp.
  - *Strophomena* sp.
  - *Zygospira kentuckiensis* James
    - sp.

Drakes Formation—Continued
- Bryozoa:
  - *Amplexopora* spp.
  - *Batostomella* cf. *B. delicatula* (Nicholson)
    - sp.
  - *Bythopora* aff. *B. dendrina* (James)
  - *Constellaria* sp.
  - *Crepipora* sp.
  - *Cyphotrypa*? sp.
  - *Dekayia* cf. *D. nicklesi* (Ulrich and Bassler)
    - spp.
  - Fenestellid, indet.
  - *Gortanipora bassleri* (Nickles)
    - sp.
  - *Gortanipora*? sp.
  - *Graptodictya* sp.
  - *Heterotrypa subramosa* (Ulrich)
  - *Homotrypa ramulosa* Bassler
    - sp.
  - *Homotrypa*? sp.
  - *Parvohallopora ramosa* (d'Orbigny)
  - *Peronopora* cf. *P. decipiens* (Rominger)
  - *Stictopora*? sp.
  - *Stigmatella* cf. *S. personata* Ulrich and Bassler
    - sp.
- Coelenterata:
  - Anthozoa:
    - *Calapoecia huronensis* Billings
    - *Favistina stellata* (Hall)
    - *Foerstephyllum vacuum* (Foerste)
    - *Grewingkia canadensis* (Billings)
    - *Saffordophyllum floweri* Browne
    - "*Streptelasma*" spp.
    - *Tetradium approximatum* Bassler
      - sp.
- Conodonta:
  - *Aphelognathus grandis* Branson and Mehl
  - *Rhipidognathus symmetricus* Branson, Mehl and Branson
- Mollusca:
  - Gastropoda:
    - *Liospira* aff. *L. micula* (Hall)
      - *vitruvia*? (Billings)
      - cf. *L. vitruvia*? (Billings)
    - *Liospira*? sp. indet.
    - *Loxoplocus* (*Lophospira*) *bowdeni* (Safford)
    - *Murchisonia*? sp. indet.
  - Pelecypoda:
    - *Ambonychia* sp. indet.
    - *Caritodens demissa* (Conrad)
      - cf. *C. demissa (Conrad)*
      - *sp.*
    - "*Ctenodonta*" aff. "*C.*" *longa* (Ulrich)
    - *Ctenodonta* sp.
    - *Cycloconcha* sp.
    - Cyrtodontids
    - *Lyrodesma major* (Ulrich)
    - *Modiolopsis* aff. *M. modiolaris* (Conrad)
      - sp.
- Stromatoporoidea:
  - *Aulacera cylindrica* (Foerste)
    - *plummeri* Galloway and St. Jean
  - *Labechia huronensis* (Billings)
- Rowland Member:
  - Arthropoda:
    - Ostracoda:
      - *Coelochilina*? sp.

Drakes Formation—Continued
- Rowland Member—Continued
  - Arthropoda—Continued
    - Ostracoda—Continued
      - *Ctenobolbina* sp.
      - *Eridoconcha* sp.
      - *Glymmatobolbina*? sp.
      - *Isochilina* sp.
      - *Krausella* sp.
      - *Laccoprimitia* sp.
      - *Leperditella* sp.
      - *Milleratia cincinnatiensis* (Miller)
      - ?*Platybolbina (Rimabolbina)* sp.
      - *Pseudotallinnella*? sp.
      - *Schmidtella*? sp.
      - Smooth ostracodes, indet.
  - Brachiopoda:
    - *Hebertella occidentalis* (Hall)
      - sp.
    - *Platystrophia ponderosa* Foerste
      - sp.
    - *Rafinesquina* sp.
  - Bryozoa:
    - *Amplexopora* spp.
    - *Batostomella* sp.
    - *Bythopora* aff. *B. dendrina* (James)
    - *Crepipora* sp.
    - *Cyphotrypa*? sp.
    - *Dekayia* cf. *D. nicklesi* (Ulrich and Bassler)
      - spp.
    - *Graptodictya* sp.
    - *Homotrypa*? sp.
    - *Parvohallopora ramosa* (d'Orbigny)
    - *Peronopora* cf. *P. decipiens* (Rominger)
    - *Stictopora*? sp.
  - Coelenterata:
    - Anthozoa:
      - *Tetradium* sp.
  - Conodonta:
    - *Aphelognathus grandis* Branson and Mehl
    - *Rhipidognathus symmetricus* Branson, Mehl and Branson
  - Mollusca:
    - Pelecypoda:
      - *Ambonychia* sp. indet.
      - *Caritodens demissa* (Conrad)
        - cf. *C. demissa* (Conrad)
      - "*Ctenodonta*" aff. "*C.*" *longa* (Ulrich)
      - *Cycloconcha* sp.
      - *Lyrodesma major* (Ulrich)
      - *Modiolopsis* aff. *M. modiolaris* (Conrad)
        - sp.
  - Marble Hill Bed:
    - Arthropoda:
      - Ostracoda:
        - ?*Platybolbina* (*Rimabolbina*) sp.
    - Bryozoa:
      - *Bythopora* aff. *B. dendrina* (James)
      - *Graptodictya* sp.
      - *Peronopora* cf. *P. decipiens* (Rominger)
      - *Stictopora*? sp.
- Bardstown Member:
  - Arthropoda:
    - Ostracoda:
      - *Craspedopyxion*? sp.
      - *Ctenobolbina* sp.

Drakes Formation—Continued
Bardstown Member—Continued
Arthropoda—Continued
Ostracoda—Continued
Krausella sp.
Leperditella sp.
Milleratia cincinnatiensis (Miller)
Milleratia? sp.
Monotiopleura auriculata Guber and Jaanusson
Smooth ostracodes, indet.
Tetradella scotti Guber
Tetradella sp.
Warthinia sp.

Brachiopoda:
Hebertella occidentalis (Hall)
sp.
Hebertella? sp.
Lepidocyclus? *capax* (Conrad)
Plaesiomys subquadrata (Hall)
sp.
Platystrophia clarkvillensis Foerste
cf. *P. clarksvillensis* Foerste
cypha (James)
Rafinesquina sp.
Strophomena vetusta (James)
sp.
Zygospira modesta Hall
sp.
Bryozoa:
Amplexopora spp.
Batostoma spp.
Batostomella gracilis (Nicholson)
spp.
Bythopora dendrina (James)
aff. *B. dendrina* (James)
Crepipora sp.
Cyphotrypa? sp.
Dekayia cf. *D. nicklesi* (Ulrich and Bassler)
Eridotrypa sp.
Gortanipora bassleri (Nickles)
Graptodictya sp.
Homotrypa? sp.
Parvohallopora ramosa (d'Orbigny)
Rhombotrypa quadrata (Rominger)
Stictopora? sp.
Coelenterata:
Anthozoa:
Calapoecia huronensis Billings
Favistina stellata (Hall)
Foerstephyllum vacuum (Foerste)
Grewingkia canadensis (Billings)
"*Streptelasma*" spp.
Tetradium approximatum Bassler
Conodonta:
Aphelognathus grandis Branson and Mehl
Rhipidognathus symmetricus Branson, Mehl and Branson
Preachersville Member:
Brachiopoda:
Hebertella occidentalis (Hall)
cf. *H. occidentalis* (Hall)
sp.
Lepidocyclus? *capax* (Conrad)
Plaesiomys subquadrata (Hall)

Drakes Formation—Continued
Preachersville Member—Continued
Brachiopoda—Continued
Platystrophia annieana Foerste
attenuata McEwan
foerstei McEwan
ponderosa Foerste
cf. *P. clarksvillensis* Foerste
cf. *P. cypha* (James)
sp.
Rafinesquina sp.
Strophomena sp.
Bryozoa:
Batostomella cf. *B. delicatula* (Nicholson)
Constellaria sp.
Fenestellid, indet.
Gortanipora? sp.
Heterotrypa subramosa (Ulrich)
Homotrypa ramulosa Bassler
sp.
Parvohallopora spp.
Stigmatella cf. *S. personata* Ulrich and Bassler
sp.
Coelenterata:
Anthozoa:
Calapoecia huronensis Billings
Favistina stellata (Hall)
Foerstephyllum vacuum (Foerste)
Grewingkia canadensis (Billings)
Saffordophyllum floweri Browne
"*Streptelasma*" spp.
Tetradium approximatum Bassler
Mollusca:
Gastropoda:
Liospira aff. *L. micula* (Hall)
vitruvia? (Billings)
cf. *L. vitruvia*? (Billings)
Liospira? sp. indet.
Loxoplocus (*Lophospira*) *bowdeni* (Safford)
Murchisonia? sp. indet.
Stromatoporoidea:
Aulacera cylindrica (Foerste)
Labechia huronensis (Billings)
Otter Creek coral bed:
Brachiopoda:
Hebertella cf. *H. occidentalis* (Hall)
Platystrophia annieana McEwan
foerstei McEwan
cf. *P. cypha* (James)
Bryozoa:
Constellaria sp.
Gortanipora? sp.
Heterotrypa subramosa (Ulrich)
Homotrypa ramulosa Bassler
sp.
Parvohallopora spp.
Coelenterata:
Anthozoa:
Calapoecia huronensis Billings
Favistina stellata (Hall)
Foerstephyllum vacuum (Foerste)
Grewingkia canadensis (Billings)
Saffordophyllum floweri Browne
"*Streptelasma*" spp.
Tetradium approximatum Bassler

Drakes Formation—Continued
Preachersville Member—Continued
Otter Creek coral bed—Continued
Mollusca:
Gastropoda:
Liospira aff. *L. micula* (Hall)
vitruvia? (Billings)
cf. *L. vitruvia*? (Billings)
Liospira? sp. indet.
Loxoplocus (*Lophospira*) *bowdeni* (Safford)
Murchisonia? sp. indet.
Pelecypoda:
Caritodens sp.
Ctenodonta sp.
Cyrtodontids
Stromatoporoidea:
Aulacera cylindrica (Foerste)
Labechia huronensis (Billings)
Saluda Dolomite Member:
Arthropoda:
Ostracoda:
Monotiopleura sp.
Smooth ostracodes, indet.
Brachiopoda:
Hebertella sp.
Platystrophia sp.
Strophomena sp.
Bryozoa:
Batostomella sp.
Bythopora aff. *B. dendrina* (James)
Gortanipora bassleri (Nickles)
Homotrypa? sp.
Parvohallopora ramosa (d'Orbigny)
Coelenterata:
Anthozoa:
"*Streptelasma*" sp.
Tetradium approximatum Bassler
Leipers Limestone:
Brachiopoda:
Hebertella occidentalis (Hall)
?*Hebertella* sp.
Platystrophia ponderosa Foerste
?*Platystrophia* sp.
?*Plectorthis* sp.
Rafinesquina nasuta (Conrad)
Cumberland Formation:
Brachiopoda:
Hebertella occidentalis (Hall)
sp.
Platystrophia sp.
Zygospira? sp.
Coelenterata:
Anthozoa:
Calapoecia huronensis Billings
Favistina stellata (Hall)
Foerstephyllum vacuum (Foerste)
?*Grewingkia canadensis* (Billings)
"*Streptelasma*" spp.
Tetradium approximatum Bassler
Mollusca:
Pelecypoda:
Ambonychia alata Meek
sp.
Caritodens sp.
Opisthoptera sp. indet.
Stromatoporoidea:
Aulacera sp. cf. *A. cylindrica* (Foerste)
Labechia huronensis (Billings)

BIOSTRATIGRAPHY

By John Pojeta, Jr.

INTRODUCTION

The Ordovician rocks overlying the Lexington Limestone have been longest studied in southwestern Ohio and adjacent parts of north-central Kentucky and southeastern Indiana. In these areas, rocks of Late Ordovician age are collectively placed in the Cincinnatian Provincial Series; the Cincinnatian is divided into Edenian, Maysvillian, and Richmondian Stages.

The term Cincinnati Group was first used by Meek and Worthen (1865, p. 155): "In view of all the facts, we have concluded to propose the name Cincinnati Group * * * for this series. This name * * * carries the mind to a well-known locality, where the formation referred to is extensively developed, and its fossils so abundant that they have been thence widely distributed, both in this country and Europe. Consequently, geologists will everywhere at once understand to what particular horizon of the Lower Silurian [Ordovician of modern usage] this name refers." The name Cincinnati Group was proposed as a replacement for Hudson River Group. In their original definition, Meek and Worthen did not indicate a top or bottom for the Cincinnati Group; the name merely referred to Ordovician rocks exposed at Cincinnati, Ohio.

Orton (1873) was the first geologist to describe the rocks of southwestern Ohio and Cincinnati in detail. He (1873, p. 369) placed the boundaries of the Cincinnati Group at "* * * the Trenton Limestone below and the Upper Silurian [Lower Silurian of modern usage] above * * *. There are beds in the vicinity of Frankfort, Kentucky, that are pronounced by Meek to be unmistakably of Trenton age, as determined by the presence of certain fossils. At some point, then, between Frankfort and Cincinnati, the base of the Cincinnati Group is to be looked for."

Orton (1873) divided the Cincinnati Group into the Point Pleasant Beds, the Cincinnati Beds proper, and the Lebanon Beds. The Cincinnati Beds proper he subdivided into the River Quarry Beds, the Eden Shales, and the Hill Quarry Beds. For the lower subdivisions of the Cincinnati Group, Orton (1873, p. 376) used clastic ratios to separate the units: "In the River Quarry beds * * * there are about four feet of shale to one foot of limestone, but the shales increase in force as we ascend in the series, until at about 100 feet above low water [of the Ohio River] the proportion is more than twice as great. For the two hundred feet next succeeding, that have been styled the Eden Shales or Middle Shales, there is seldom more than one foot of stone in ten feet of ascent. * * * The third portion of the series—the Hill Quarries—have for their lower limits the beds in which the solid rock has risen again to as high a proportion as one foot in five or six of ascent. From this point upward to the completion of the group, there is no such predominance of shale as is found below. * * *"

For the top of the Hill Quarry Beds, Orton (1873, p. 394) chose a paleontologic marker: "At a height of 425 feet above low water [of the Ohio River], a belt of rock 2-10 feet in thickness occurs, that is almost entirely composed of the ventricose full-grown shells of *O[rthis] biforata* [*Platystrophia ponderosa* Foerste of modern usage]. * * * It is virtually the summit of the Cincinnati section and the base of the Lebanon beds * * *."

Thus, the initial subdivision of the Cincinnati Group was basically lithologic, although a paleontologic boundary was chosen to separate the two highest units of the group. Also, the Cincinnati Group as defined by Orton was a time-rock unit; that is, it consisted of those deposits between Trentonian and Early Silurian rocks.

Winchell and Ulrich (1897) wrote about what they called the Cincinnati Period and noted (p. cii): "There is no other locality on the continent that deserves so well to be considered the typical locality for the series of strata in question as the region about Cincinnati, Ohio. * * * The strata of the Cincinnati period as exposed in Ohio, Indiana, and Kentucky are divisible into three groups, having about the same geological value as the Chazy, Stones River, Black River, and Trenton groups of the Trenton period. * * * These three divisions correspond very nearly with the * * * Eden shales, Hill Quarry beds, and Lebanon beds of Prof. Edward Orton * * *." Winchell and Ulrich seem to have been the first workers to consider the rocks at Cincinnati as a type section for North America; they anticipated the subdivision of the Cincinnatian into three stages. For Orton's Eden Shales, Winchell and Ulrich used the term Utica Group, and for the Hill Quarry Beds they used the name Lorraine Group; in their opinion the beds at Cincinnati were clearly equivalent to those in New York with the names Utica and Lorraine. For Orton's name Lebanon Beds, Winchell and Ulrich proposed Richmond Group because Lebanon was preoccupied as a stratigraphic name.

Winchell and Ulrich excluded the Point Pleasant and River Quarry Beds from their Cincinnati Period and indicated (1897, p. xcviii) that the rocks exposed near the river at Covington, Ky., belonged to their Trenton Group. Nickles (1902, p. 58) noted that the River Quarry Beds were the same formation as the Point Pleasant Beds and that they were of Trentonian age. Thus, by the early 20th century the Cincinnati Group of southwestern Ohio and adjacent States included all Ordovician rocks above the Point Pleasant Beds. This lower limit to the sequence has been used by most workers since that time (Weiss and Norman, 1960).

The term Cincinnatian was introduced into the literature by Clarke and Schuchert (1899, p. 877) because "Probably in no other region is the succession of these faunas so complete as about Cincinnati, and this fact justifies the recognition of the term 'Cincinnatian' * * *." Schuchert and Barrell (1914, p. 25) used the term Cincinnatian for the Upper Ordovician rocks of North America. Wilmarth (1925, p. 86) wrote: "The United States Geological Survey employs the term Cincinnatian as a provincial name for the Upper Ordovician series, and ascribes to it the same limits as those given by Winchell and Ulrich in 1897 and by Clarke and Schuchert in 1899." Since that time the term Cincinnatian has been widely used by many workers for the Upper Ordovician rocks of North America. It is a time-rock unit for all those rocks that correlate with Ordovician rocks above the Point Pleasant Limestone in and around Cincinnati, Ohio.

Foerste (1905a, p. 150) proposed the name Maysville "* * * for the strata at Cincinnati hitherto identified as Lorraine." He revived Orton's name Eden for strata formerly called Utica, and retained the name Richmond for the rocks above the Maysville. He called the Eden, Maysville, and Richmond, divisions of the Cincinnatian. The reason Foerste (1905a, p. 149-150) gave for adopting local names for the subdivision of the Cincinnatian in its type area was: "* * * several changes in the nomenclature have seemed advisable. Some of these are due to the practice, which recently has become more general, of adopting distinct names for formations which formerly were considered approximately identical, whenever a study of their fossil faunas indicates that these formations were deposited in zoological provinces essentially distinct. Now, a study of the fossil lists given by Nickles * * * indicates that the rocks at Cincinnati identified as Lorraine and Utica contain faunas so different from the typical Lorraine and Utica faunas of New York as to warrant application of the principle above stated."

CINCINNATIAN STAGES

The division of the Cincinnatian into Edenian, Maysvillian, and Richmondian Stages has been widely accepted, but these names were commonly used both in a time-rock sense as stages and in a rock-stratigraphic sense as groups in the type Cincinnatian. Sweet and Bergström (1971, p. 615) strongly advocated that this dual usage of the terms Eden, Maysville, and Richmond be ended: "Even though the Eden, Maysville, and Richmond Groups are recognizable lithostratigraphic units in at least the northern part of the Cincinnati Region, it has become increasingly confusing to use those terms, even locally, for rock-stratigraphic units. That is, since shortly after the turn of the century * * * and persistently since at least 1908 * * *, the names Eden (or

Edenian), Maysville (or Maysvillian), and Richmond (or Richmondian) have been used widely for stadial divisions of the North American Upper Ordovician, and for some years it has seemed unwise to use these names in a dual sense. Thus, in this report we use Edenian, Maysvillian, and Richmondian as stadial terms, * * * and we refer to rocks of Edenian, Maysvillian, and Richmondian age in the Cincinnati Region by using names from the current lithostratigraphic classification * * *." Herein, the terms Edenian, Maysvillian, and Richmondian are also used only as stages.

The Edenian Stage includes all those rocks that can be correlated with the Eden Shales of Orton (1873) at Cincinnati, Ohio. Orton's Eden Shales included all the rocks from the River Quarry Beds (Point Pleasant Beds) to the base of the Hill Quarry Beds, the basal unit of which is now the Fairview Formation. At Cincinnati, Edenian-age rocks are placed within the single lithostratigraphic unit known as the Kope Formation. The Maysvillian Stage includes all those rocks that can be correlated with the rocks at Cincinnati that Winchell and Ulrich (1897) called the Lorraine Group and that Foerste (1905a) renamed the Maysville. Winchell and Ulrich (1897, p. cii) noted that their term Lorraine Group was for strata previously known as the Hill Quarry Beds, whose top was placed by Orton (1873) at the top of the rubbly beds containing *Platystrophia ponderosa*. At Cincinnati, these rubbly beds marking the top of the Maysvillian [Lorraine] cap some of the hills. Nickles (1902) and Foerste (1905a) placed the upper boundary of the Maysvillian of Ohio slightly higher, but most workers have left the boundary where it was placed by Orton (Bucher and others, 1939, 1945; Caster and others, 1955, 1961; Weiss and Norman, 1960; Sweet and Bergström, 1971; Sweet, 1979). Rocks of Maysvillian age at Cincinnati are included in the Fairview Formation, the Grant Lake Limestone, and the lowermost part of the Bull Fork Formation. The Richmondian Stage includes all the rocks that can be correlated with the Upper Ordovician rocks in and around Cincinnati above the *Platystrophia ponderosa* beds. Within the city of Cincinnati, only early Richmondian rocks are present, and they are assigned to the Bull Fork Formation.

ZONATION

The earliest zonations of the Cincinnatian were defined by Nickles (1902, 1903), primarily on the basis of bryozoans, and by Cumings (1908) and Cumings and Galloway (1913) largely on the basis of brachiopods. The zone names given by these authors have been little used since their proposals; instead, the geographic names that they also applied to the zones have been widely used and treated as formational names. Foerste (1903, 1904, 1905b, 1909, 1910, 1912a, b) did much of the early work of correlating the Ordovician sequences of Kentucky, Ohio, and Indiana, and often used the formational names of Nickles and Cumings.

Most recent work dealing with the biostratigraphy of the Ordovician rocks above the Lexington Limestone in the area of outcrop around the Jessamine dome has been based on conodonts (Sweet and others, 1959; Pulse and Sweet, 1960; Kohut and Sweet, 1968; Seddon and Sweet, 1971; Sweet and Bergström, 1971; Sweet and others, 1974; Ethington and Sweet, 1977). This information was synthesized by Sweet (1979), who compared the classical stage boundaries for the Edenian, Maysvillian, and Richmondian with the conodont zones of Bergström (1971a, b) and the numbered conodont faunas of Sweet and others (1971). Bergström and Sweet (1966) also considered the correlation of the rocks below the Cincinnatian that crop out toward the center of the Jessamine dome; in their work they used the terminology of the new lithostratigraphic classification of Ordovician rocks in the tristate area of Kentucky, Ohio, and Indiana.

Bergström and Sweet (1966), O. L. Karklins (in Cressman and Karklins, 1970, p. 21-23), and Sweet and Bergström (1970) showed that the upper part of the Lexington Limestone at its reference section in central Kentucky correlates with Edenian rocks exposed around Cincinnati, Ohio. Sweet and Bergström (1970) suggested that south of Frankfort, Ky., and near Clays Ferry, Ky., the upper 70 to 80 ft of the Lexington Limestone correlate with the lower 70 to 80 ft of the Kope Formation at Cincinnati and thus are Edenian in age. Karklins indicated that bryozoans of Late Ordovician aspect occur as low as the upper part of the Brannon Member of the Lexington Limestone at the reference section of the Lexington, about 100 ft below the top of the formation (Cressman and Karklins, 1970, p. 21, 23).

Correlations based on conodont biostratigraphy of the formations cropping out near Cincinnati were presented by Sweet and Bergström (1971, fig. 2) and Sweet (1979). Figure 50, based on the work of Sweet, shows diagrammatically the approximate time relations of most major lithologic units of the Blue Grass region and adjacent regions in Ohio and Indiana. The diagrammed correlations indicate that many of the formations are markedly diachronous. The Middle Ordovician-Upper Ordovician boundary at Cincinnati is by definition placed at the contact between the Kope Formation (Eden Shales of Orton, 1873) and the Point Pleasant Tongue of the Clays Ferry Formation (River Quarry Beds of Orton, 1873). In central Kentucky, however, both the Lexington Limestone and the Clays Ferry Formation cross this series boundary, although to the southeast the Lexington is entirely of Middle Ordovician age. Locally in northern central Kentucky, the Point Pleasant Tongue of the Clays Ferry also crosses the boundary between the Middle and Upper Ordovician (Sweet, 1979). Thus, all rock units above the Clays Ferry Formation and, generally, those above the Lexington Limestone are Late Ordovician. In outcrops of the Clays Ferry Formation (including the Point Pleasant Tongue) and the Lexington Limestone, it is necessary to determine where the Middle Ordovician-Upper Ordovician boundary is, although the general picture is that the top of the Lexington Limestone (bottom of the Clays Ferry Formation) "* * * becomes younger southeastward from the northwestern part to the center of the Cincinnati Region, then older toward the southeastern part of the area of exposure" (Sweet and Bergström, 1971, p. 619). The lower part of the Lexington Limestone and all rock units below it that crop out in central Kentucky are Middle Ordovician.

Sweet (1979) estimated the thickness of the Ordovician section from the base of the Lexington Limestone to the Ordovician-Silurian boundary at 1,040 ft; this thickness forms his composite section for Ordovician rocks above the Tyrone Limestone of the High Bridge Group in the tristate area of Kentucky, Ohio, and Indiana. He noted that in the composite section the base of the Edenian Stage (base of Cincinnatian Provincial Series) is at 315 ft (base of the Kope Formation); the base of the Maysvillian Stage is at 545 ft (base of the Fairview Formation); the base of the Richmondian Stage is at 755 ft (top of *Platystrophia ponderosa* beds); and that neither the top nor the base of the range of any conodont species coincides with any of these boundaries.

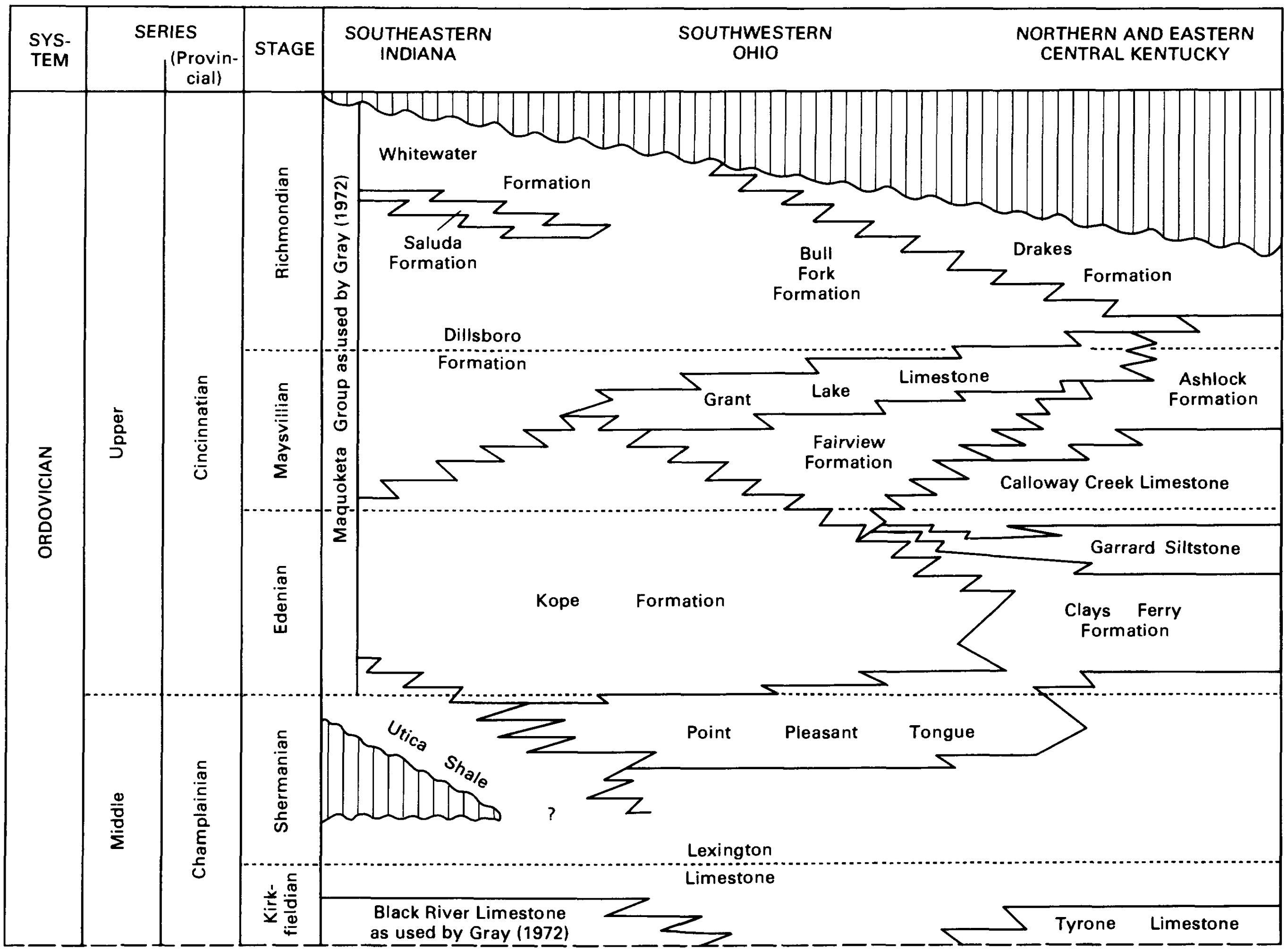

FIGURE 50.—Approximate stratigraphic relations of major lithostratigraphic units in Cincinnati region. Time-stratigraphic framework determined from studies of conodonts of Cincinnati region. Modified from Sweet (1979, fig. 3, p. G13).

Thus, none of the Cincinnatian stages can be characterized specifically by any conodont species.

Sweet (1979) also noted that in the composite section three conodont zones are present (fig. 51). Rocks from 40 to 200 ft above the base of the composite section contain *Amorphognathus tvaerensis* Bergström, and so at least the upper part of the *A. tvaerensis* Zone (Bergström, 1971a) is present in the lower part of the Lexington Limestone. Rocks between 205 and 580 ft above the base of the composite section contain specimens of *A. superbus* (Rhodes), which defines the *A. superbus* Zone of Bergström; thus, this zone ranges into rocks of early Maysvillian age. Sweet noted that specimens of *Amorphognathus* from rocks 585 to 785 ft above the base of the composite section are assigned to *A. ordovicicus* Branson and Mehl, although the holodontiform element that is distinctive of this species has not yet been found in the Cincinnati region. If these specimens are correctly assigned to *A. ordovicicus*, then the *A. ordovicicus* Zone of Bergström (1971a, b) is present near the top of the type Cincinnatian (fig. 51). The boundary of the zone between *A. superbus* and *A. ordovicicus* is close to the boundary between the Caradocian and Ashgillian Series of the British Ordovician sequence (Bergström, 1971b), and so this boundary may be within the lower 40 ft of the Maysvillian Stage of the type Cincinnatian.

Sweet and others (1971) described a succession of conodont faunas based on the Middle and Upper Ordovician rocks of what is termed the North American Midcontinent Province; Bergström's zones are from what is called the North Atlantic Province. Conodonts from both provinces occur in the type Cincinnatian (fig. 51). Sweet and others (1971) did not call their conodont faunas zones, because they were uncertain whether the succession of faunas represents an unbroken sequence. In terms of their faunas (Sweet, 1979), representatives of fauna 8 occur in the lower 55 ft of the composite section; rocks between 55 and 200 ft above the base of the composite section contain representatives of fauna 9; species characteristic of fauna 10 are present in rocks 200 to 410 ft above the base of the composite section; conodonts from rocks 410 to 655 ft above the base of the composite section indicate fauna 11; and species characteristic of fauna 12 are present from 800 to 1,040 ft above the base of the composite section. Rocks between 655 and 800 ft above the base of the composite section have not yet yielded conodonts that are restricted to

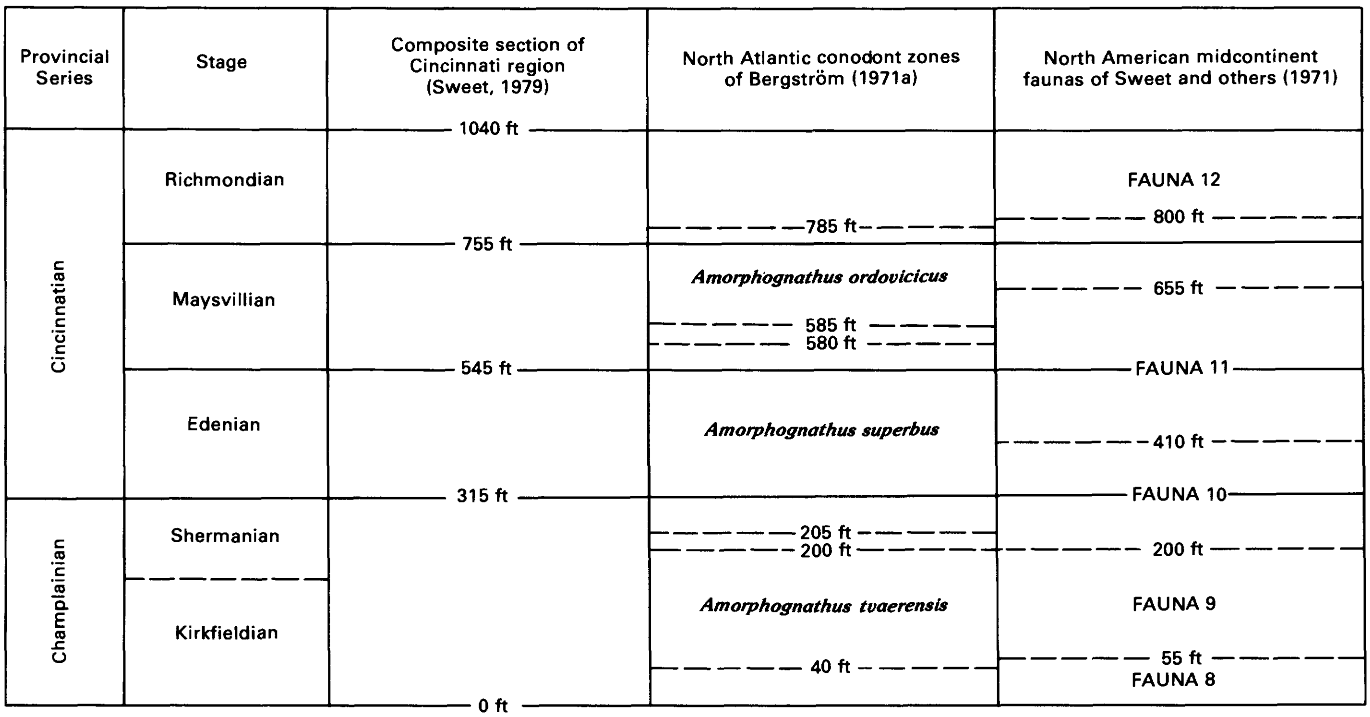

FIGURE 51.—Comparison of known ranges of conodont zones of Bergström (1971a) with conodont faunas of Sweet and others (1971) in type Cincinnatian Provincial Series. Also shown is thickness of composite section of Sweet (1979) and his placement of stage boundaries of the Cincinnatian Provincial Series.

any of the several faunas described by Sweet and others (1971). The interval of fauna 10 crosses the boundary between the Middle Ordovician and Upper Ordovician.

Strata of Cincinnatian age are present throughout much of the Central and Eastern United States. An interregional view of the stratigraphic relations of formations in the Cincinnati, Ohio, area was given by Sweet and Bergström (1976). Despite the general abundance of Late Ordovician fossils, stages of the Cincinnatian Provincial Series are difficult to recognize outside the type region because many megafaunal elements of the Cincinnatian appear to be indigenous to the eastern midcontinent region and other elements seem to have different stratigraphic ranges or distributions elsewhere (Sweet and Bergström, 1976, p. 125). At present, more detailed information is available on the distribution of conodont species than of any other group of fossils. Figure 52, drawn from their work, shows correlations with Ordovician strata in adjacent States based on the conodont biostratigraphy.

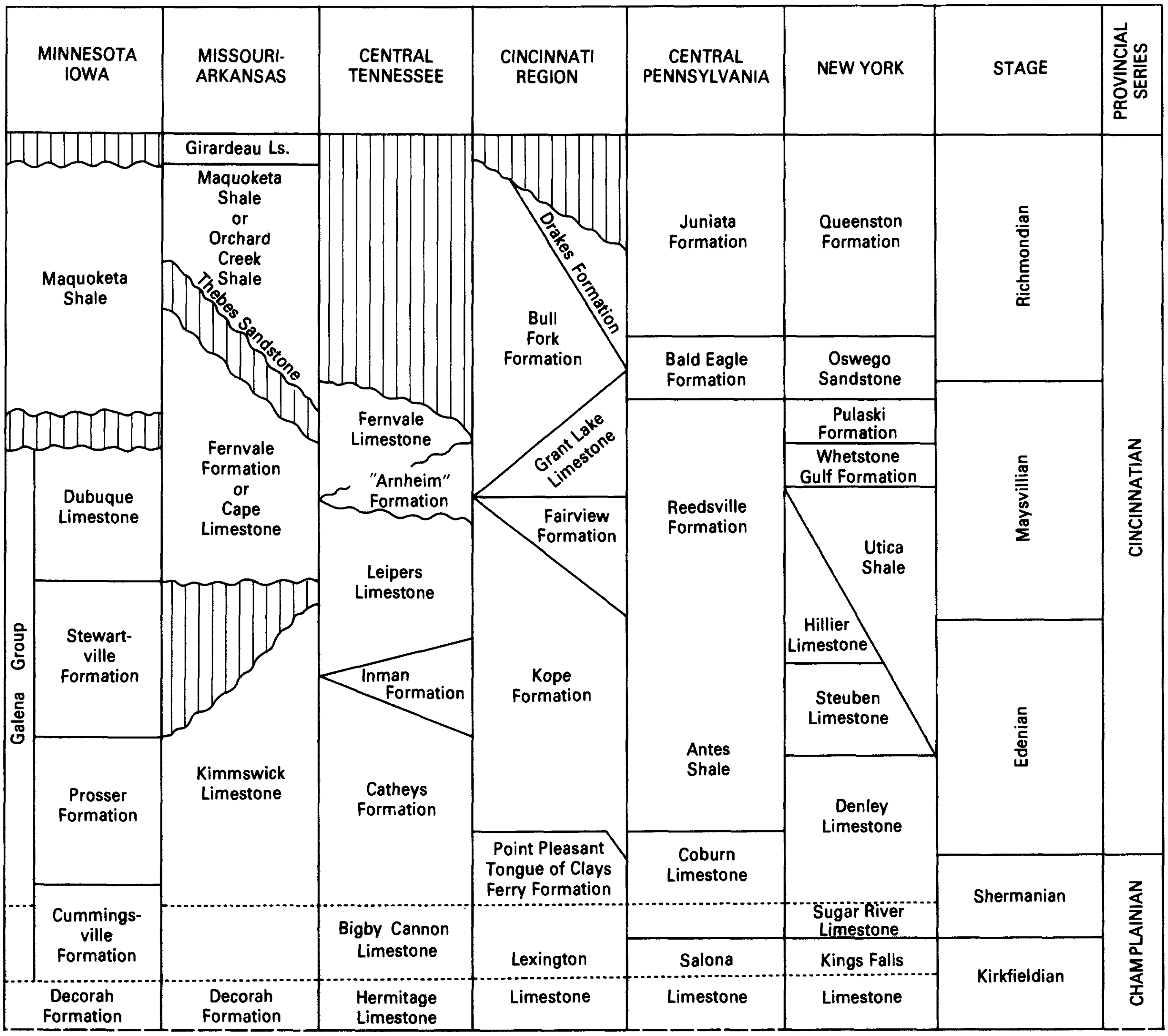

FIGURE 52.—Correlation of upper Champlainian (Middle Ordovician) and Cincinnatian (Upper Ordovician) formations in selected regions of Central and Eastern United States. Exact position of formational contacts relative to those in adjacent columns is unknown. Modified from Sweet and Bergström (1976, fig. 3, p. 132-133).

LITHOFACIES

The Upper Ordovician strata of Kentucky are composed chiefly of limestone, shale, and dolomite; these major rock types intergrade and vary in texture, bedding, and fossil content. The strata may be divided into lithofacies that have distinctive features by which they may be separated from adjacent units (see Weller, 1958, p. 633).

In this report, the Upper Ordovician strata in the study area are divided into 14 lithofacies, whose salient features are listed in table 5; outcrop characteristics of the lithofacies are illustrated in figures 53 through 56. The lithofacies are generalized intergrading rock units that are differentiated on the basis of composition, texture, bedding, and relative abundance of fossils. Vertical gradations range from a few inches to a few tens of feet; lateral gradations are commonly obscure and take place over a distance of several miles. The limits set on the intergrading characters of the lithofacies in table 5 and the locations of cutoffs of laterally intergrading lithofacies in plates 6 and 7 are based on our experience in mapping Ordovician strata in Kentucky. Many of the lithofacies could be further subdivided; those shown are known to have a broad extent.

The lithofacies of this report are in part the same as those described by Weir and Peck (1968) for Upper Ordovician strata in Kentucky on the east side of the Cincinnati arch and by Weir, Peterson, and Swadley (1979a) for Upper Ordovician strata cropping out in the Blue Grass region and near the Cumberland River in Kentucky. They resemble the lithofacies described by Wilson (1949) for Ordovician strata in central Tennessee and by Hay (1977) for Upper Ordovician strata in southeastern Indiana.

The lithofacies described in table 5 are assembled into four groups. In most of these groups the lithofacies are more alike than different and more difficult to separate from one another than from lithofacies of another group. Group I lithofacies are characterized by various proportions of planar beds of fossiliferous limestone and shale. Group II lithofacies are characterized by nodular beds of limestone. Group III is a miscellaneous assemblage of lithofacies characterized by units of limestone of fairly uniform grain size or by units of siltstone. Group IV lithofacies are dolomitic. The term or phrase used to designate each lithofacies is based on the more detailed description given in table 5.

Lithofacies A, "thin-bedded fossiliferous limestone," is mostly poorly sorted fossil-fragmental limestone in uneven to even, in part lensing beds interlayered with partings and thin sets of shale or, less commonly, of siltstone (fig. 53*A*). It generally contains some interstratified thin nodular beds of limestone like many beds in lithofacies E, and some lenses of calcarenite like the beds in lithofacies H. Lithofacies A is distinguished from other lithofacies of group I by its preponderance of limestone and the variety of its thin bedding. It is irregularly resistant and forms ledgy, moderate slopes. Lithofacies A is best exemplified by the lower two-thirds of the Calloway Creek Limetone.

Limestone and shale are approximately equal in lithofacies B, "even-bedded fossiliferous limestone and shale." The shale content is about the same throughout or decreases upward in the lithofacies; siltstone also is present in minor amounts. Figures 53*B* and 53*C* show the bedding characteristic of this lithofacies in different formations. The lithofacies is irregularly resistant and forms ledgy, gentle to moderate slopes. Lithofacies B is distinguished from lithofacies A by its greater shale content, from lithofacies C by its generally thicker more continuous beds of limestone and its siltstone content, and from lithofacies D by its lesser shale content. Lithofacies B is characteristic of the Fairview and Clays Ferry Formations.

Limestone and shale also are approximately equal in lithofacies C, "even-bedded fossiliferous shale and limestone" (fig. 53*D*), but this lithofacies differs from lithofacies B by having an upward increase in shale content and by containing discontinuous limestone beds. Lithofacies C differs from lithofacies A by its lesser limestone content and from lithofacies D by its lesser shale content. It is irregularly resistant and forms moderate to gentle slopes, commonly ledgy near the base and steepening near the top because of the upward increasing content of shale. Lithofacies C is characteristic of the Bull Fork Formation.

Lithofacies D, "shale and fossiliferous limestone," contains a large percentage of shale in thick sets interlayered with lesser amounts of limestone and minor siltstone. Lithofacies D is relatively nonresistant, commonly forms moderate slopes, and is well exposed only in roadcuts (fig. 53*E*). Lithofacies D is exemplified by the Kope Formation.

Lithofacies E, "nodular-bedded limestone and shale," is dominant in group II lithofacies. Figures 54*A* through 54*C* show the characteristic bedding of this lithofacies in three different formations. Lithofacies E lacks the calcarenite of the otherwise similar lithofacies F and contains more limestone than lithofacies G. The limestone is conspicuously poorly sorted and commonly contains large whole fossils and fossil fragments in a muddy micrograined to fine-grained matrix. Locally the limestone contains abundant oncolites (fig. 20). Much shale is intimately intermixed with the limestone. The lithofacies crops out poorly and generally forms gentle to moderate slopes with few ledges; outcrops weather readily to a rubble of rounded limestone fragments,

TABLE 5.—*Description of lithofacies of Upper Ordovician strata exposed in Kentucky*

Composition (percent)	Texture	Bedding	Fossils
I. Planar-bedded fossiliferous limestone and shale lithofacies			
A. Thin-bedded fossiliferous limestone:			
Limestone (70-80)	Fossil fragmental, matrix fine to medium grained.	Thin beds (1-4 in.), laterally variable in thickness and continuity.	Abundant brachiopods and bryozoans.
Shale, calcitic (15-25)	Silty to clayey	Crude laminae in sets 1-6 in. thick and as partings.	Sparse to common brachiopods.
Siltstone, calcitic (5)	Fine to coarse silt	Smooth-surfaced thin beds (1-3 in.), laterally continuous and uniform in thickness.	Sparse brachiopods.
B. Even-bedded fossiliferous limestone and shale:			
Limestone (30-60)	Fossil fragmental, matrix, micrograined to fine grained or medium to coarse grained.	Thin to medium beds (1-10 in.), laterally continuous and uniform in thickness.	Abundant brachiopods and bryozoans.
Shale, calcitic (30-60)	Silty to clayey	As in lithofacies A	Sparse brachiopods and bryozoans.
Siltstone, calcitic (5-10)	Fine silt	Smooth-surfaced thin to thick beds (1-6 in.), laterally discontinuous and variable in thickness.	Sparse brachiopods.
C. Even-bedded fossiliferous shale and limestone:			
Limestone (40-60)	Fossil fragmental; matrix chiefly fine grained but ranging from micrograined to coarse grained, in part muddy.	Thin beds (1-4 in.), laterally continuous and variable in thickness, some nodular; also as lenticles and partings in shale.	Common to very abundant; chiefly brachiopods, bryozoans, and corals.
Shale, calcitic (40-60); commonly increasing in abundance upward.	Clayey to silty	Crude laminae in sets 1-24 in. thick	Sparse to common brachiopods and bryozoans.
D. Shale and fossiliferous limestone:			
Shale (60-80)	Clayey to silty	Crude laminae in sets 1-20 ft thick	Sparse brachiopods and bryozoans.
Limestone (20-30)	Fossil fragmental; matrix very fine to coarse grained.	Thin to medium beds (1-18 in.), laterally continuous and uniform to uneven in thickness.	Abundant brachiopods and bryozoans, common crinoids and trilobites.
Siltstone (0-5)	Fine silt	Thin (1-4 in.) even beds and sets of laminae.	Sparse brachiopods.
II. Nodular-bedded fossiliferous limestone and shale lithofacies			
E. Nodular-bedded fossiliferous limestone and shale:			
Limestone (60-90)	Fossil fragmental, micrograined to fine-grained muddy matrix.	Obscure thin beds (1-4 in.) made up of closely packed nodular lenticles grading to irregularly wavy thin lenses; in part laterally discontinuous and variable in thickness.	Abundant brachiopods and bryozoans.
Shale, calcitic (10-40)	Clayey to silty	Partly in crude laminae in thin lenses (1-4 in.); partly intermixed and intergrading with limestone.	
F. Nodular-bedded limestone and calcarenite:			
Limestone (70-90)	Mostly as in lithofacies E and also (5-25 percent) medium to coarse grained.	Mostly as in lithofacies E. Calcarenite in planar sets, commonly 1-3 ft thick, of thin planar beds or wavy low-angle crossbeds.	Abundant brachiopods and bryozoans; stromatoporoids locally abundant.
Shale (10-30)	Clayey to silty	Partly in crude laminae in thin lenses (1-4 in.); partly intermixed and intergrading with limestone.	

Mudstone (70-80)	Clayey to silty and clayey	Crude laminae in obscure sets several feet thick, containing abundant nodular lenticles 0.5-2 in. in diameter of very calcitic mudstone and muddy limestone.	Abundant brachiopods and bryozoans; gastropods, pelecypods, ostracodes, and fragments of trilobites and crinoid stems locally common to abundant.
Limestone (20-30)	Micrograined to fine grained, muddy; in part fossil fragmental.	Thin beds (1-4 in.), laterally discontinuous and variable in thickness, and as lenticles scattered through mudstone.	
III. Transitional lithofacies			
H. Calcarenite:			
Limestone (100)	Medium to very coarse grained	Thin to medium beds (1-10 in.) and thin sets (1-4 in.) of low-angle crossbeds.	Sparse brachiopods.
I. Micrograined limestone:			
Limestone (60-90)	Cryptograined to medium grained, chiefly micrograined to fine grained.	Thin beds (1-4 in.), planar to wavy, laterally continuous and uniform to variable in thickness.	Sparse to abundant ostracodes; brachiopods, gastropods, and scolithoid markings locally common.
Shale, calcitic (10-40)	Clayey to silty	Crude laminae in thin sets (1-2 in.) and as partings.	
J. Siltstone and shale:			
Siltstone, calcitic (60-80)	Fine to coarse silt	Even thin beds (2-6 in.) and lentcular and contorted, thin to medium beds (6-24 in.).	Sparse to common brachiopods.
Shale (10-20)	Silty to clayey	Crude laminae in sets 0.5-3 in. thick.	Sparse brachiopods.
Limestone (5-10)	Fossil fragmental, matrix medium coarse grained, silty.	Thin lentils (1-6 in.)	Sparse to common brachiopods and crinoids.
IV. Dolomite lithofacies			
K. Dolomitic mudstone:			
Calcitic to dolomitic mudstone grading to muddy dolomite and to muddy dolomitic limestone.	Micrograined	Obscure laminae and very thin beds (less than 1 in.), laterally continuous and uniform in thickness, in sets a few inches to a few feet thick.	Absent to very sparse, chiefly bryozoans.
L. Dolomitic mudstone and dolomite:			
Muddy dolomite grading to dolomitic mudstone (75-90).	Micrograined	As in lithofacies K	Generally absent; sparse bryozoans.
Dolomite grading to dolomitic limestone (10-25).	Very fine to medium grained	Thin to medium beds (1-8 in.), laterally continuous and fairly uniform, irregularly interstratified in unit as single beds and grouped in sets as much as 4 ft thick.	Sparse to abundant bryozoans; brachiopods generally sparse.
M. Dolomite and calcitic dolomite:			
Dolomite interbedded and intergrading with calcitic dolomite and minor limestone (80-100).	Micrograined to medium grained	Obscure laminae, in part crude, and very thin beds (less than 1 in.), laterally continuous and uniform in thickness, in sets a few inches to a few feet thick.	Generally absent; sparse brachiopods and bryozoans.
Dolomitic to calcitic mudstone (0-20).	Clayey to silty	As in lithofacies K and L.	
N. Dolomitic limestone and mudstone:			
Dolomitic limestone and limestone (50-75).	Micrograined	Medium beds (4-18 in.)	Common to abundant ostracodes; gastropods, brachiopods, and bryozoans sparse to locally abundant.
Calcitic mudstone (25-50)	Silty	Obscure laminae in thin sets (1-4 in.)	Sparse bryozoans.

whole large globular brachiopods, and pieces of bryozoans. Lithofacies E is characteristic of most of the Grant Lake Limestone, the upper part of the Leipers Limestone, the Reba Member of the Ashlock Formation, and the upper part of the Calloway Creek Limestone.

Lithofacies F, "nodular-bedded limestone and calcarenite," resembles lithofacies E but also contains conspicuous ledge-forming lenses or sets of beds of fairly well sorted medium- to coarse-grained calcarenite. The calcarenite is interlayered with the nodular-bedded limestone and commonly makes up about 20 percent of the unit; locally, calcarenite is dominant (fig. 54*D*). Small- to medium-scale planar and trough sets of low-angle crossbeds are common in the calcarenite. The lithofacies commonly forms an irregular slope marked

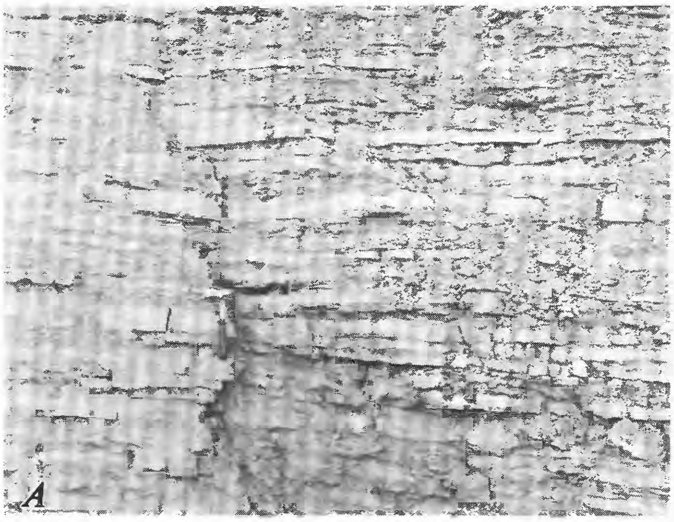

FIGURE 53*A*.—Group I: lithofacies A, "thin-bedded fossiliferous limestone" (lower part of Calloway Creek Limestone). Roadcut on Interstate Highway I-75, Richmond North quadrangle, east-central Kentucky.

FIGURE 53*B*.—Group I: lithofacies B, "even-bedded fossiliferous limestone and shale" (Fairview Formation). Roadcut on Kentucky Highway 1449, Maysville East quadrangle, northeast Kentucky. Horizontal rule is 1 ft long; vertical stick is 2 ft long.

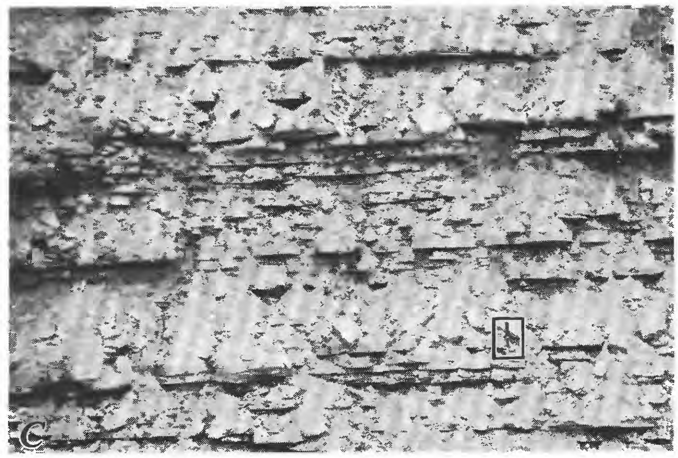

FIGURE 53*C*.—Group I: lithofacies B, "even-bedded fossiliferous limestone and shale" (Clays Ferry Formation). Roadcut on Blue Grass Parkway, Chaplin quadrangle, central Kentucky.

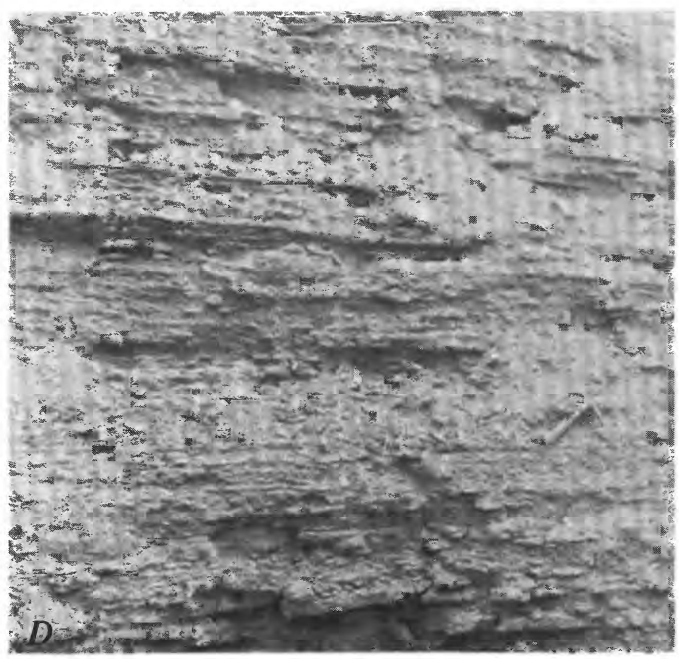

FIGURE 53*D*.—Group I: lithofacies C, "even-bedded fossiliferous shale and limestone" (Bull Fork Formation). Roadcut on U.S. Highway 42, Bedford quadrangle, western north-central Kentucky. Compare with figures 46 and 60.

by calcarenite ledges, alternating with gentle slopes underlain by nodular-bedded limestone and shale. Lithofacies F occurs in the lower part of the Leipers Limestone and locally in the Grant Lake Limestone.

FIGURE 53*E*.—Group I: lithofacies D, "shale and fossiliferous limestone" (Kope Formation). Roadcut near junction of Ohio Highway 128 and Interstate Highway I-74, Addyston quadrangle, southwestern Ohio.

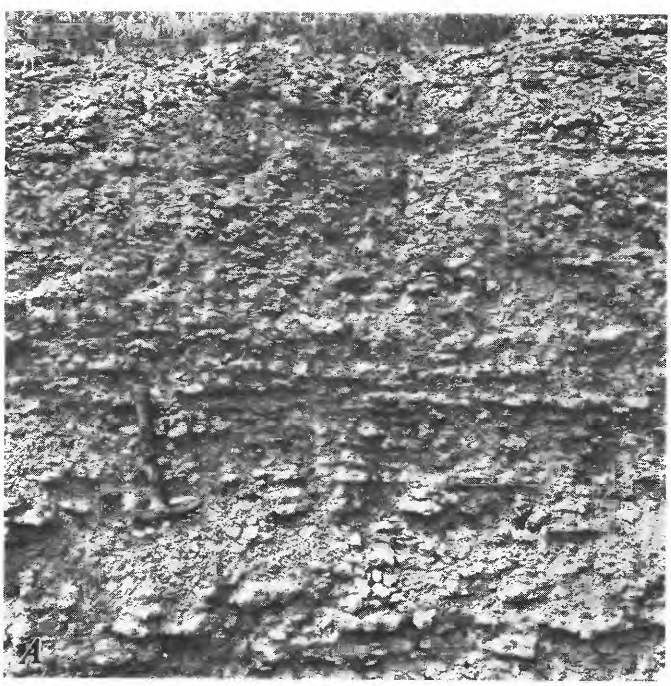

FIGURE 54*A*.—Group II: lithofacies E, "nodular-bedded limestone and shale" (Grant Lake Limestone). Near junction of Kentucky Highway 55 and Interstate Highway I-64, Simpsonville quadrangle, northwestern central Kentucky.

Lithofacies G, "nodular-bedded mudstone," is mostly calcitic nodular-bedded mudstone or shale and limestone interlayered with a few sets of nodular-bedded limestone like that in lithofacies E (fig. 54*E*). The lithofacies is nonresistant and forms a gentle slope, commonly with a rubble of limestone fragments and large fossils. Lithofacies G occurs in the Stingy Creek Member of the Ashlock Formation.

Lithofacies H, "calcarenite," is made up chiefly of medium- to coarse-grained limestone, commonly in thin sets of low-angle crossbeds (fig. 55*A*). Although the limestone is largely made up of fossil fragments, whole fossils are rare. The limestone of lithofacies H resembles the calcarenite interlayered with nodular-bedded limestone in lithofacies F; thin lenses of similar calcarenite also occur rarely in lithofacies A, B, and C. Lithofacies H is set apart from other calcarenitic lithofacies to show an exceptionally persistent ledge-forming unit in north-central Kentucky that was formerly included locally in the Grant Lake Limestone and elsewhere in the Calloway Creek Limestone (Weir, Peterson, and Swadley, 1979a), and is here assigned to the Grant Lake Limestone (pl. 7).

Lithofacies I, "micrograined limestone," consists of limestone interbedded with lesser amounts of shale. The limestone, dominantly micrograined to fine grained but ranging from cryptograined to medium grained, is in thin planar to wavy and nodular beds interlayered with thin sets of calcitic shale (figs. 55*B*, 55*C*). Fossils are

FIGURE 54*B*.—Group II: lithofacies E, "nodular-bedded limestone and shale" (Reba Member of the Ashlock Formation). Roadcut on U.S. Highway 27, Lancaster quadrangle, southwestern east-central Kentucky. Rule is 1 ft long.

generally sparse, but ostracodes are common in the limestone. Scolithoid markings—vertical tubes a few millimeters in diameter and a few centimeters long—occur at the tops of some beds. Lithofacies I is in part similar to lithofacies E in bedding style but differs from lithofacies E in having a fairly uniform much finer grain size and a sparsity of fossils. Lithofacies I is exemplified by the Sunset Member of the Bull Fork and Ashlock Formations and by the Gilbert Member of the Ashlock Formation.

Lithofacies J, "siltstone and shale," is dominantly fine to coarse silt interbedded with shale and minor limestone (fig. 55*D*). The siltstone grades locally to very silty limestone, but most limestone in this lithofacies is more or less silty medium- to coarse-grained shelly

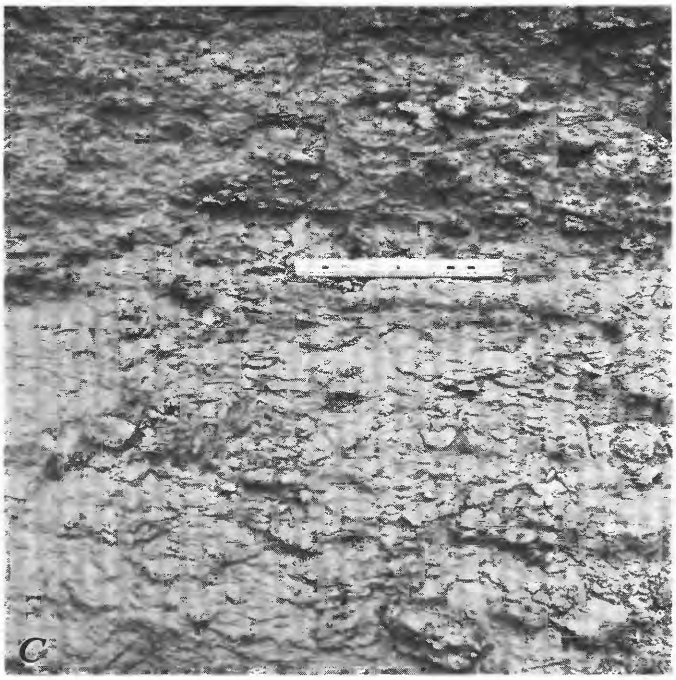

FIGURE 54*C*.—Group II: lithofaces E, "nodular-bedded limestone and shale" (upper part of Leipers Limestone). Roadcut on Kentucky Highway 90, Waterview quadrangle, south-central Kentucky. Rule is 1 ft long.

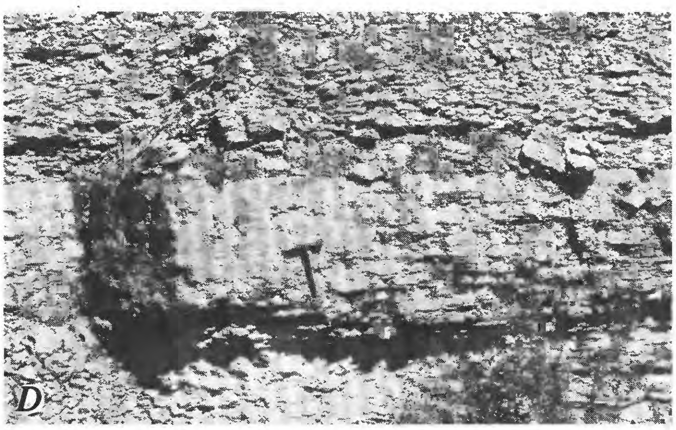

FIGURE 54*D*.—Group II: lithofacies F, "nodular-bedded limestone and calcarenite" (Grant Lake Limestone). Outcrop along unnamed stream about 1 mi west of Owingsville, Owingsville quadrangle, northern east-central Kentucky.

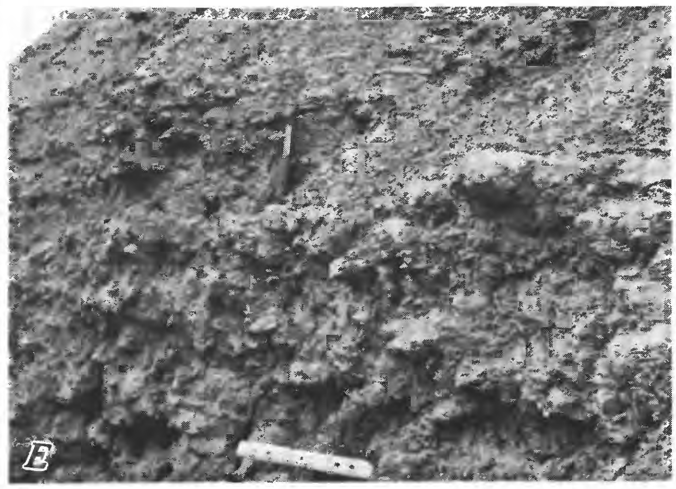

FIGURE 54*E*.—Group II: lithofacies G, "nodular-bedded mudstone" (Stingy Creek Member of the Ashlock Formation). Roadcut on U.S. Highway 27 Lancaster quadrangle, southwestern east-central Kentucky. Rule is 1 ft long.

FIGURE 55*A*.—Group III: lithofacies H, "calcarenite" (c) (Grant Lake Limestone). Roadcut on U.S. Highway 42, Bedford quadrangle, western north-central Kentucky.

limestone in wispy lenses. Interbedded shale is in very thin sets, commonly only a few inches thick. One characteristic of this lithofacies is bedding contorted into ball-and-pillow structures (fig. 15). Although siltstone in minor amounts is characteristic of lithofacies A, B, and D, lithofacies J is distinguished by the dominance of siltstone. The lithofacies is irregularly resistant and commonly forms moderate slopes studded with ledges of firmly cemented calcitic siltstone. Lithofacies J is exemplified by the Garrard Siltstone.

Lithofacies K, "dolomitic mudstone," which characterizes several members, ranges in composition from calcitic to dolomitic mudstone and grades to muddy, micrograined dolomite and limestone. The strata are in thin to medium sets of obscure laminae and very thin beds (figs. 56*A*-56*C*). Outcrop faces commonly appear almost uniform. Megafossils are generally absent. The

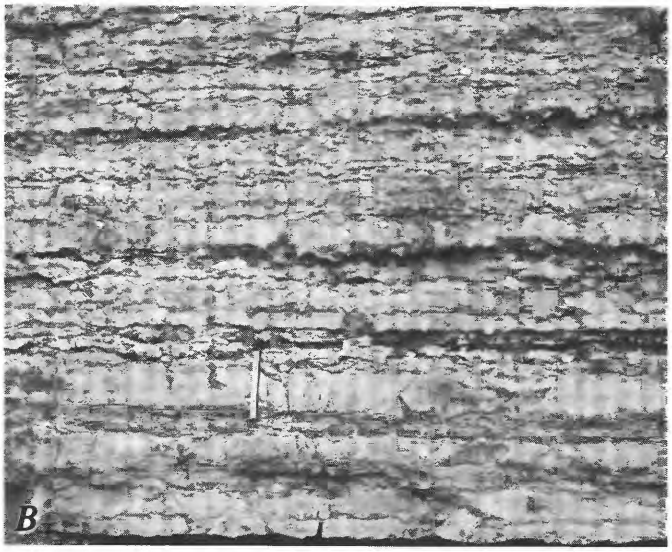

FIGURE 55*B*.—Group III: lithofacies I, "micrograined limestone" (Gilbert Member of the Ashlock Formation). Roadcut on U.S. Highway 27, Lancaster quadrangle, southwestern east-central Kentucky. Rule is 1 ft long.

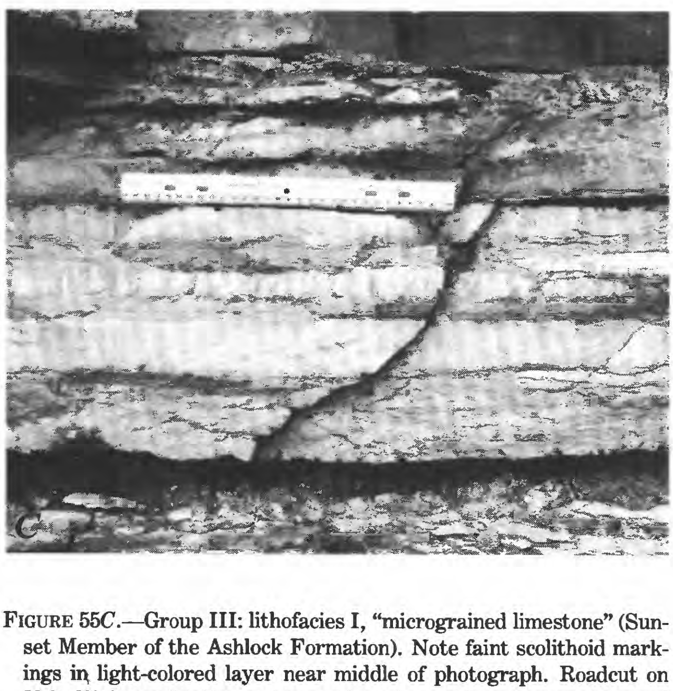

FIGURE 55*C*.—Group III: lithofacies I, "micrograined limestone" (Sunset Member of the Ashlock Formation). Note faint scolithoid markings in light-colored layer near middle of photograph. Roadcut on U.S. Highway 27, Lancaster quadrangle, southeastern east-central Kentucky. Rule is 1 ft long.

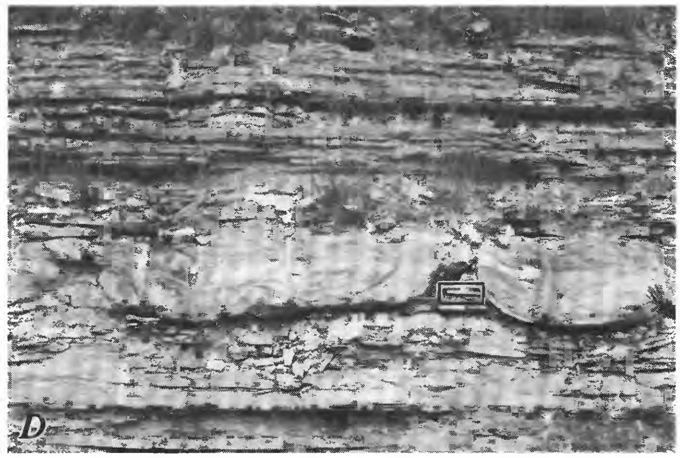

FIGURE 55*D*.—Group III: lithofacies J, "siltstone and shale" (Garrard Siltstone). Compare ball-and-pillow structures near middle of photograph with those shown in figure 15. Roadcut on U.S. Highway 27, Hustonville quadrangle, southeastern central Kentucky. Rule between pillows is 1 ft long.

FIGURE 56*A*.—Group IV: lithofacies K, "dolomitic mudstone" (Tate Member of the Ashlock Formation). Roadcut on U.S. Highway 27, Lancaster quadrangle, southwestern east-central Kentucky.

lithofacies is relatively nonresistant and forms gentle slopes. Lithofacies K contains less dolomite than lithofacies L and M and less limestone than lithofacies M. The Terrill and Tate Members of the Ashlock Formation and the Rowland Member of the Drakes Formation in east-central and central Kentucky are made up mostly of lithofacies K.

Lithofacies L, "dolomitic mudstone and dolomite," is the same as lithofacies K except that it contains ledge-forming sets of beds of very fine grained to medium-grained dolomite and dolomitic limestone (figs. 56*D*, 56*E*). Megafossils, mostly poorly preserved bryozoans, are generally confined to the dolomite and dolomitic limestone. Lithofacies L is characteristic of the lower part of the Saluda Dolomite Member and the Preachersville Member of the Drakes Formation.

Lithofacies M, "dolomite and calcitic dolomite," resembles lithofacies J and K but is much more dolomitic. It is composed of dolomite intergraded and interbedded with calcitic dolomite, locally with dolomitic to calcitic mudstone, and, more rarely, with fine-grained limestone, all commonly in obscure very thin beds and laminae (figs. 56*F*, 56*G*). The lithofacies is fairly resistant and commonly forms rounded cliffs. Lithofacies M characterizes the Cumberland Formation and the upper part of the Saluda Dolomite Member of the Drakes Formation.

Lithofacies N, "dolomitic limestone and calcitic mudstone," is much more calcitic than the other lithofacies of group IV. It is dominantly micrograined muddy dolomitic limestone in medium planar beds interlayered with substantial amounts of calcitic shale in thin sets (fig. 56*H*). The dolomitic limestone generally contains ostracodes and locally contains fragments of mollusks and bryozoans. The lithofacies is irregularly resistant and commonly forms uneven gentle slopes. Lithofacies N is characteristic of the Rowland Member of the Drakes Formation in north-central Kentucky.

RELATION OF LITHOFACIES TO FORMAL STRATIGRAPHIC UNITS

A general correspondence between the lithofacies and formal stratigraphic units is apparent on the lithofacies maps (pls. 6, 7); formations and members are commonly made up of a single lithofacies or of a few closely related lithofacies. This correspondence between lithofacies units and map units was one aim of the mapping program, and in many parts of the study area, relatively homogeneous rock-stratigraphic units were mapped individually. In parts of the area, however, the formations and members are composed of unrelated lithofacies, because the more readily mapped contacts differ from the relatively obscure (gradational or poorly exposed) boundaries of major lithofacies, or because the

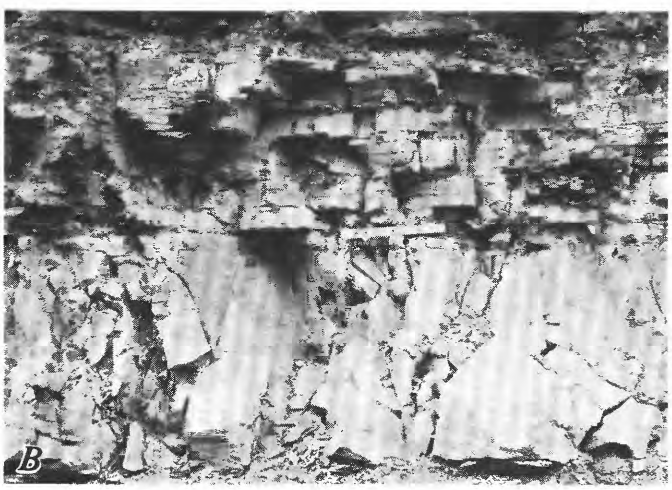

FIGURE 56*B*.—Group IV: lithofacies K, "dolomitic mudstone" (Terrill Member of the Ashlock Formation). Roadcut on U.S. Highway 27, Hustonville quadrangle, southeastern central Kentucky. Rule near center of photograph is 1 ft long.

FIGURE 56*C*.—Group IV: lithofacies K, "dolomitic mudstone" (Rowland Member of the Drakes Formation). Roadcut on U.S. Highway 27, Stanford quadrangle, southeastern central Kentucky.

continuity and interrelation of some lithofacies were originally uncertain.

Several formal units are extended in this report to match more fully the known extent of their characteristic lithofacies. Thus, the Terrill and Reba Members of the Ashlock Formation are extended farther westward and the Bull Fork Formation extended farther southward than shown on the pertinent geologic quadrangle maps or on earlier diagrams showing lithofacies and stratigraphic names in Kentucky (see Weir, Peterson, and Swadley, 1979a).

Several discrepancies between lithofacies units and formally named map units remain. Chief among these are the interrelations of the nodular-bedded limestone and shale of lithofacies E with the Calloway Creek Limestone, the Grant Lake Limestone, and the Leipers Limestone in the southern part of the study area. Because we wish to maintain a close tie between the nomenclature used in this report and that used on the published geologic quadrangle maps, we have not further revised the stratigraphic names.

FIGURE 56*D*.—Group IV: lithofacies L, "dolomitic mudstone and dolomite" (Preachersville Member of the Drakes Formation). Roadcut on Interstate Highway I-64, Preston quadrangle, northern east-central Kentucky. Rule is 1 ft long.

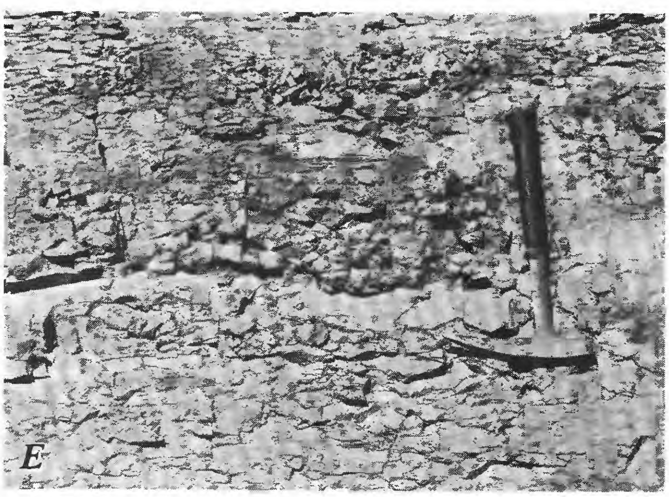

FIGURE 56*E*.—Group IV: lithofacies L, "dolomitic mudstone and dolomite" (lower part of Saluda Dolomite Member of the Drakes Formation). Roadcut on U.S. Highway 150, Maud quadrangle, western central Kentucky.

AREAL RELATIONS

The diagrams of the lithofacies (pls. 6, 7) show that the groups of lithofacies and certain individual lithofacies have common vertical and lateral associations. Planar-bedded fossiliferous limestone and shale lithofacies of group I are dominant in the lower part of

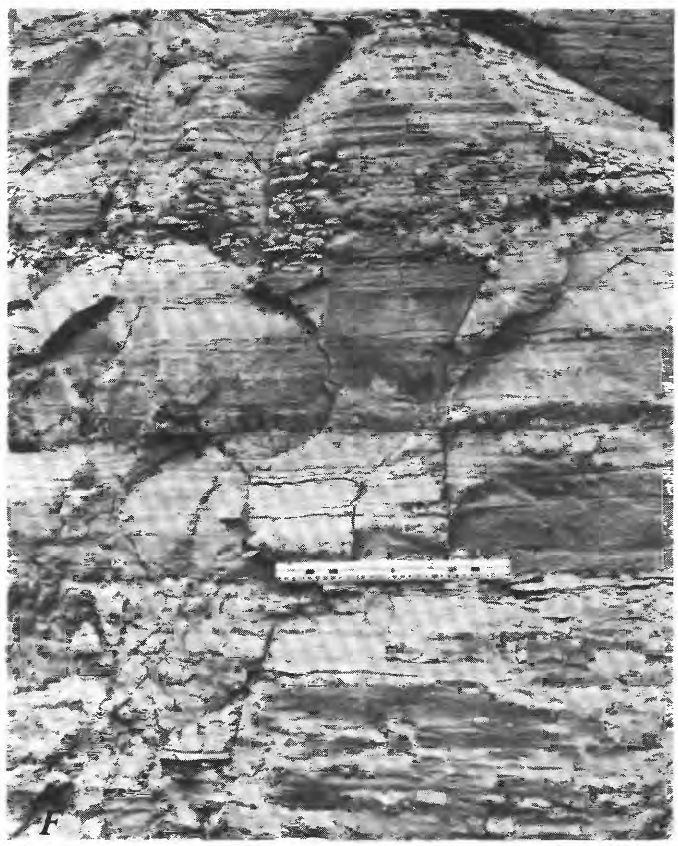

FIGURE 56*F*.—Group IV: lithofacies M, "dolomite and calcitic dolomite" (Cumberland Formation). Roadcut on Kentucky Highway 90, Burkesville quadrangle, south-central Kentucky. Rule is 1 ft long.

the Ordovician section. Nodular-bedded fossiliferous limestone and shale lithofacies of group II are dominant in the middle part of the section and are succeeded by dolomitic lithofacies of group IV or by a recurrence of group I lithofacies capped by lithofacies of group IV.

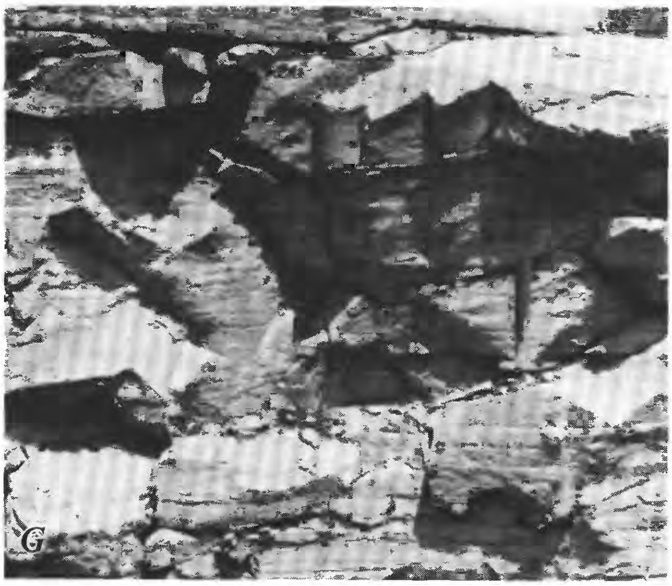

FIGURE 56*G*.—Group IV: lithofacies M, "dolomite and calcitic dolomite" (upper part of Saluda Dolomite Member of Drakes Formation). Intersection of Kentucky Highways 155 and 841, Jeffersontown quadrangle, southwestern north-central Kentucky.

FIGURE 56*H*.—Group IV: lithofacies N, "dolomitic limestone and calcitic mudstone" (Rowland Member of the Drakes Formation). Roadcut on Interstate Highway I-64, Fisherville quadrangle, southwestern north-central Kentucky.

The transitional lithofacies of group III are mostly in the middle part of the section. Individual lithofacies commonly intergrade laterally with others of the same group. Many individual lithofacies and all groups of lithofacies intergrade laterally or vertically with the nodular-bedded lithofacies of group II. Calcarenite of lithofacies H and micrograined limestone of lithofacies I are nearly everywhere overlain by nodular-bedded lithofacies.

The general pattern of vertical and lateral associations of lithofacies has many local exceptions, owing to the intertonguing of relatively thin units. A conspicuous example of such intertonguing occurs between Stanford and Mount Sterling, Ky., where thin layers of dolomitic mudstone of lithofacies K alternate with layers of nodular-bedded limestone and mudstone of lithofacies E and F and micrograined limestone of lithofacies I (cross sec. *B-B'*, pl. 7).

Group I lithofacies are dominant in the northern part of the State (fig. 57). Lithofacies of group II are widespread but are thinnest in the north (fig. 58). Group IV lithofacies are thickest in the southern and southeastern parts of the study area (fig. 59).

Several individual lithofacies have a narrowly restricted distribution. Nodular-bedded limestone and calcarenite of lithofacies F is found only in the northwestern part of the study area and in two small patches in the northeastern part of the area. Nodular-bedded mudstone of lithofacies G (the Stingy Creek Member of the Ashlock Formation) occurs only in the southeastern part of the study area. The calcarenite of lithofacies H, somewhat arbitrarily separated from the nodular-bedded limestone and calcarenite of lithofacies F, is discriminated only in western north-central Kentucky. The micrograined limestone of lithofacies I (the Gilbert and Sunset Members of the Ashlock Formation) and the siltstone and shale of lithofacies J (virtually equivalent to the Garrard Siltstone, fig. 16) are confined to the southern central and east-central parts of the State. Dolomitic limestone and mudstone of lithofacies N is restricted to the western part of the study area, where it forms the distal part of the Rowland Member of the Drakes Formation.

DEPOSITIONAL ENVIRONMENTS

Depositional environments of individual lithofacies are here inferred mainly from composition, grain size, sedimentary structures (especially bedding), fossil content, and the interrelations of lithofacies. All the lithofacies appear to have been deposited on an extensive shelf, mostly in open marine waters of shallow to moderate depth but locally in intertidal and supratidal environments. Contrasts between depositional environments probably were mostly caused by areal differences in depth, bottom relief, and water turbulence, which resulted in differences in water temperature and chemistry. Because the sea was generally shallow, small changes in sea level could have caused large changes in the distribution of environments along the shelf.

The interlayered planar-bedded fossiliferous limestone and shale characteristic of group I lithofacies indicate deposition in environments of markedly fluctuating energy. The thicknesses of the interlayered shale units, which in this group range from several inches in lithofacies A and B to a few tens of feet in lithofacies D, reflect several interrelated factors. Chief among these are the supply of terrigenous material, the strength and persistence of currents, and periods or areas of relatively quiet, possibly deeper water in which clay and silt settled to the bottom. The origin of the limestone beds characteristic of group I lithofacies has generally been ascribed to variations in mud supply, bottom currents, topography, and the nature of the bottom-dwelling fauna. Harris and Martin (1979), who reviewed previous ideas on the origin of Cincinnatian limestones, emphasized the baffling effect of expanding benthic patches colonized successively by flat brachiopods, bryozoans, and crinoids. This fauna gave protection to an abundant varied biota, whose shells accumulated to form limestone beds until the biota was suffocated by terrigenous mud brought in by storms.

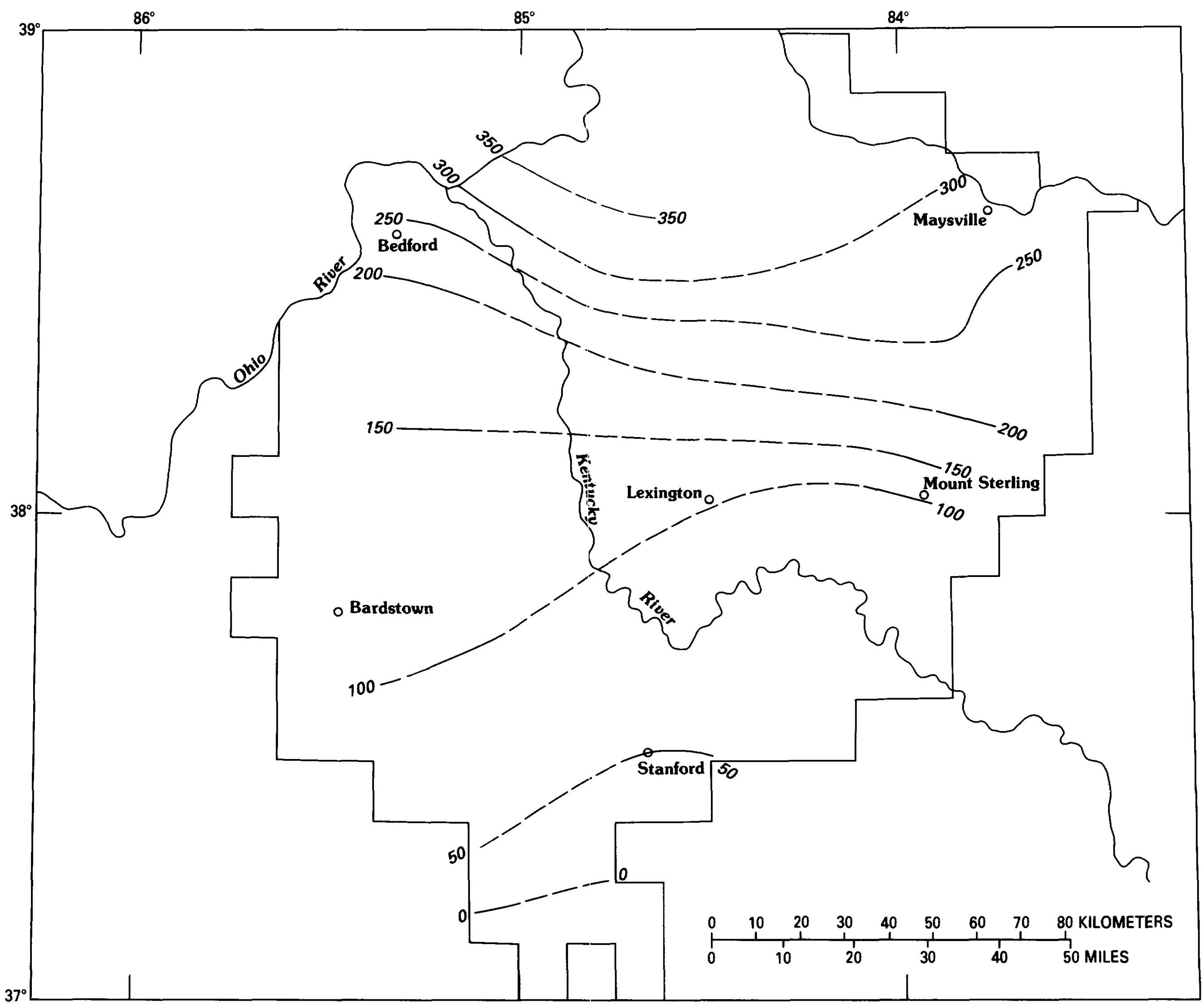

FIGURE 57.—Part of Kentucky, showing thickness of group I lithofacies, planar-bedded fossiliferous limestone and shale. Contour interval, 50 ft; contours dashed where conjectural.

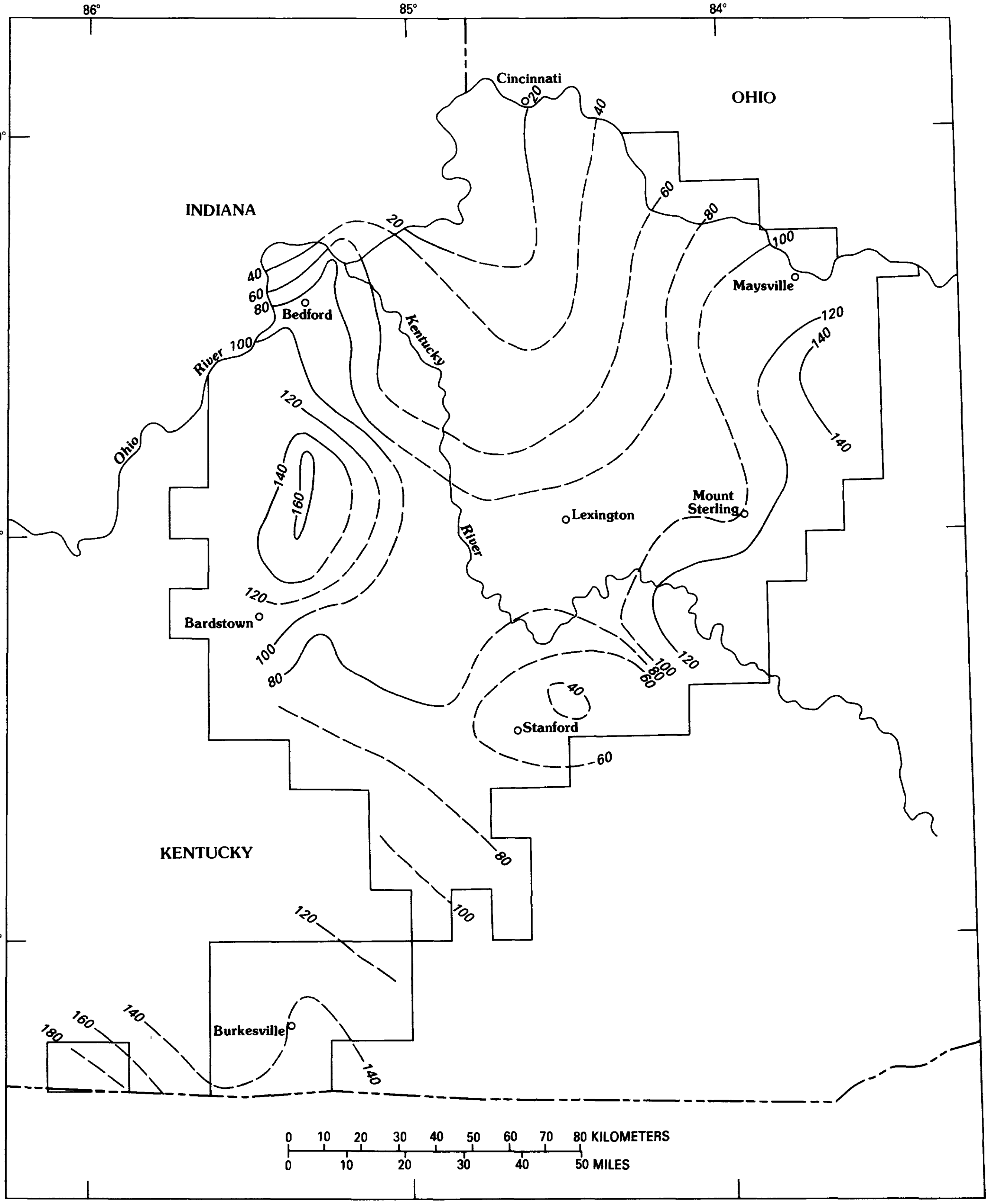

FIGURE 58.—Part of Kentucky, showing thickness of group II lithofacies, nodular-bedded fossiliferous limestone and shale. Contour interval, 20 ft; contours dashed where conjectural.

Current-induced sedimentary structures, though rarely conspicuous, occur sporadically throughout all group I lithofacies. Chief among these structures are ripple marks, the largest having amplitudes of several inches and wavelengths of several feet. Some bedding surfaces of well-sorted fine-grained limestone and of calcitic shale show faint scour marks and tool marks. Lenses and sheetlike bodies of calcarenite, most common in lithofacies B and D, contain trough and planar sets of low-angle crossbeds. Such structures are most probably the result of local shoaling and the effects of storm waves.

The varied benthic fauna of many of the richly fossiliferous limestone beds in group I lithofacies is strong evidence that these rocks were laid down where oxygen and light were abundantly available—that is, in the zone of the shelf where photosynthesis was possible. In clear coastal and turbid oceanic waters of the present oceans, the limiting depth where the light is sufficient for photosynthesis to support large populations of plants and animals ranges from about 25 to 45 m (82-148 ft); in turbid coastal waters this limit is at a depth of only 1 to 12 m (3-39 ft) (Holmes, 1957, p. 123). The common sparsity of fossils in shale and siltstone layers of these lithofacies may generally result from choking off of the benthos by turbid waters. The relatively thick and unfossiliferous layers of shale in lithofacies D, however, likely reflect at least in part deposition on deeper parts of the shelf. The

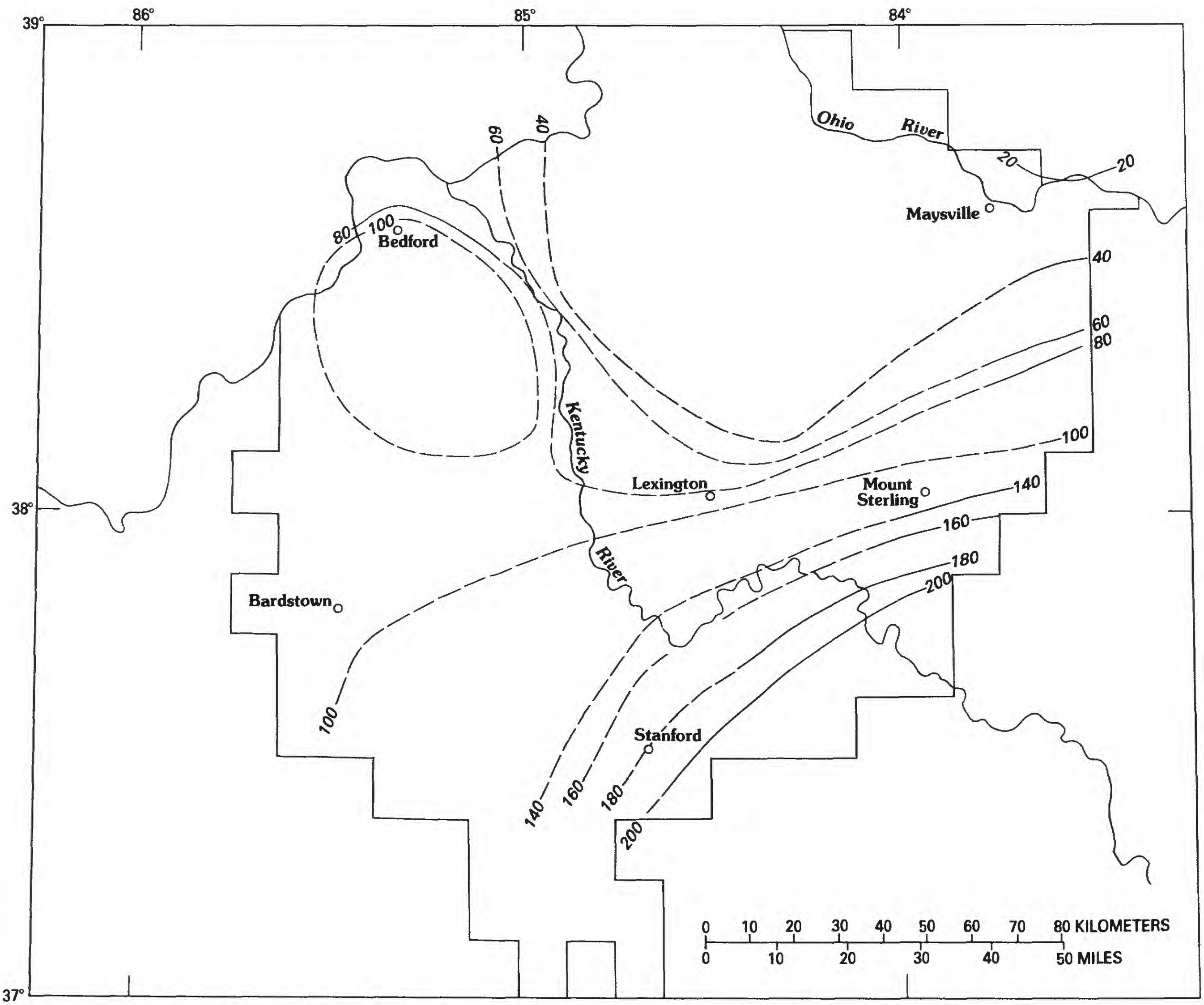

Figure 59.—Map of part of Kentucky, showing thickness of group IV lithofacies, dolomite. Variations in thickness due to post-Ordovician unconformity not shown. Contour interval, 20 ft; contours dashed where conjectural.

fine grain size and the general absence of current structures indicate that these layers were deposited below wave base. The absence of fossil shells and burrows in many of the shale layers of lithofacies D suggests that they were laid down below the zone of effective photosynthesis.

Although the absolute depths represented by the lithofacies of group I cannot be specified with assurance, the relative depths represented by the four lithofacies can be inferred from their interrelations as well as their lithic, structural, and faunal characteristics. All these lithofacies must overlap considerably in the ranges of depth of their depositional environments, because they intergrade and include layers that could be classified as other lithofacies. Lithofacies D, judged to be the deepest, shallows slightly into adjoining lithofacies B, which in turn shallows into locally adjoining lithofacies A. Lithofacies C includes many strata apparently laid down in fairly shallow water, because it is the most fossiliferous lithofacies in group I and contains zones of abundant colonial corals, of stromatoporoids, and of horn corals. A broad cut-and-fill structure, as much as 8 ft deep and estimated to be more than 300 ft across, in lithofacies C near Owingsville, Ky. (Weir, 1970, p. 56), attests to strong local currents (fig. 60). Lithofacies C grades vertically and perhaps also laterally into lithofacies containing sedimentary structures indicative of intermittent subaerial exposure. Lithofacies D, as exemplified by Edenian strata (the Kope Formation) near the junction of Indiana, Ohio, and Kentucky, was estimated by Anstey and Fowler (1969, p. 674-675) on the basis of its fauna and lithology to have been deposited in water 20 m (66 ft) or more deep. Bucher's (1917) estimate of the depth of depositional environments, based on analysis of ripple marks in strata here included in lithofacies B and D, of a maximum of about 25 m (82 ft) was considered reasonable (Weiss and others, 1965, p. 64; Cressman, 1973c, p. 45, 46). The depositional environments of group I lithofacies, including the shallower lithofacies A and C, probably ranged in depth from several meters to a few tens of meters (about 10 to 100 ft).

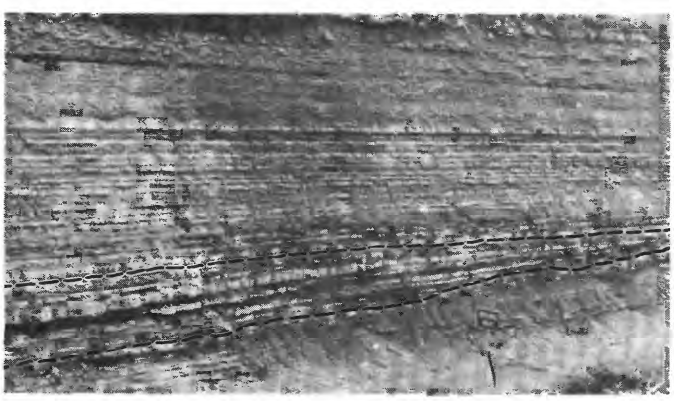

FIGURE 60.—Upper member of the Bull Fork Formation, showing variations in bedding characteristic of unit. Dashed lines denote boundaries of cut-and-fill structure, which is about 8 ft thick at left edge of photograph. Prominent ledge near top of exposure is stromatolitic limestone. Roadcut on exit road from Interstate Highway I-64 to U.S. Highway 60, Colfax quadrangle, northern east-central Kentucky.

The lithofacies of group II are characterized by nodular bedding and by abundant thick-shelled globoid brachiopods and large fragments of stout branching bryozoans—forms adapted for living in turbulent water. The nodular bedding in part is the result of compaction of poorly sorted fine-grained material around large fossils but probably is mostly the result of vigorous burrowing by an unpreserved soft-bodied infauna. The abundant micrite in the groundmass of limestone of group II lithofacies was probably derived from skeletal grains comminuted by burrowing organisms, and from algae. The locally common to abundant concentrically layered oncolites present in lithofacies E and F indicate deposition in continually wave-agitated shallow waters (Logan and others, 1964, p. 81).

In general aspect, lithofacies E closely resembles the Millersburg Member of the Lexington Limestone, whose depositional environment was inferred by Cressman (1973c, p. 43) to be aerated, moderately turbulent, normal marine water less than 15 m (49 ft) deep. Lithofacies F was in part deposited in water shallower than lithofacies E. The lenticular and sheetlike bodies of calcarenite common in lithofacies F indicate shoaling and the formation of bars within the subtidal zone, because the sorting and crossbedding in these calcarenite units resulted from strong currents, probably in part storm induced. The currents washed and winnowed the mixed-grained material, removed most of the fine grains, and piled up the coarse grains in dune forms having thin sloping layers. Lithofacies G also was probably deposited in shallower waters than lithofacies E. Abundant clay and silt in this lithofacies indicate turbid water, although abundant fossils show that this turbidity was counteracted by available sunlight at shallow depths. The fossils are less abraded in lithofacies G; thus, the depositional environment was less vigorously agitated than the environments of other lithofacies of group II. The depth at which oxygen production and consumption balance one another in natural populations in present-day turbid coastal water is only 1 to 12 m (3 to 39 ft) (Holmes, 1957, p. 123); therefore, the depositional environments of group II lithofacies probably ranged in depth from about 1 to 15 m (3 to 49 ft).

The lithofacies of group III are not closely related in lithic and faunal characters or in depositional environments. They have in common that they form a minor part of rock sequences classified as lithofacies of groups I or II, and also that in places they constitute the major part of thin but persistent rock bodies.

The calcarenite of lithofacies H, which resembles the calcarenite interstratified with nodular limestone in lithofacies F, represents deposition in zones of high energy on the carbonate shelf where strong wave action abraded fossil fragments and removed some fine-grained material. Crossbedding in the calcarenite suggests that the rock formed in part as subtidal bars on broad shoals that were only a few meters deep.

The sparse fossil content of many beds of micrograined to fine-grained limestone in lithofacies I suggests that some beds of lithofacies I were deposited in waters of above-normal salinity or temperature. The occurrence of megafossils in some beds, however, indicates that much of lithofacies I was deposited in normal marine waters. The general continuity of the bedding suggests that the rocks of this lithofacies were laid down in relatively quiet water, although the local presence of oncolites shows that at times the water was agitated. An environment that would fit these conditions is a lagoon, although no evidence of a bar or similar physical feature separating lithofacies I from other lithofacies has been recognized. Possibly these beds were deposited in subtidal waters, no more than a few meters deep, where evaporation at times raised the salinity of a very thin prism of water of the Cincinnatian sea.

Calcitic siltstone dominant in lithofacies J is a minor, though noticeable, constituent of most group I lithofacies. It seems likely, therefore, that the depositional environment of lithofacies J probably resembled the environments of the planar-bedded fossiliferous limestone and shale of group I lithofacies: Open marine waters several meters to a few tens of meters deep. Some siltstone contains well-preserved whole fossils, but most of the siltstone is relatively barren. These variations in the abundance of fossils suggest that the general sparsity of shells in the siltstone is more likely due to the cutting off of light and oxygenation by silt-laden waters than to deposition at depths below the zone of photosynthesis. Limestone of lithofacies J is in thin lensing beds, largely made up of fragments of brachiopods and crinoids, and abraded whole brachiopods. These characters suggest that the limestone accumulated from debris washed in by storm waves from the neighboring shelf where environments were more favorable to life.

The ball-and-pillow structures common in the siltstone of lithofacies J may have more than one origin. The bulbous masses are not at a constant stratigraphic horizon, nor do they have an apparent common orientation, and so they do not seem to be the result of sliding down a submarine slope. They resemble structures, produced experimentally by Kuenen (1958), resulting from the foundering of sand into clay made semifluid by shock. Kuenen suggested that an earthquake shock might be the triggering mechanism in nature. Some of the ball-and-pillow structures are immediately overlain by a bed of coarse-grained fossil-fragmental limestone suggestive of a storm-laid layer. The siltstone beds may have been contorted when storm waves rendered the underlying layers of silt and clay fluid.

The lithofacies of group IV are all more or less dolomitic and display sedimentary structures suggestive of very shallow water and occasional subaerial exposure. Most units are made up of laminae or very thin beds; stratification ranges from well defined in some dolomite to obscure in much of the mudstone. Fossil mud cracks (fig. 38) occur in all these lithofacies except lithofacies N. Indigenous fossils, common to abundant in the limestone and dolomitic limestone of lithofacies N, indicate that this lithofacies was deposited in open marine waters. Partly abraded fossils in the other lithofacies of this group suggest that some of the fossils in these lithofacies were washed in by storm waves from environments more favorable for the benthic fauna. Rip-up clasts of dolomitic mudstone, apparently derived from the erosion of mud flakes formed on desiccated surfaces, in dolomite of lithofacies M (fig. 48) in south-central Kentucky indicate intermittent subaerial exposure. Fresh rock in group IV lithofacies is dominantly light grayish green, but a few grayish-red layers in lithofacies L in northeast Kentucky suggest that this area contains some originally reddish terrigenous material and may have been closer to the shelf borderlands.

Lithofacies K, L, and M are interpreted to have been deposited chiefly in supratidal and high-intertidal environments. Fossiliferous beds in lithofacies L indicate much subtidal deposition. Differences between lithofacies K and M seem mostly caused by the admixture of a large amount of clay and silt in lithofacies K, apparently supplied from the seaward side of the shelf.

PALEOGEOGRAPHY

In this section, the history of the study area is inferred from the changes through time in the distribution of lithofacies, which reflect depositional environments controlled by the paleogeography. Time planes through the section exposed in the study area are uncertain, because the post-Lexington rocks have not been zoned in detail throughout this area. Paleontologic studies to date, however, strongly suggest that most, possibly all, the lithic units are time transgressive (fig. 50).

In the absence of detailed fossil controls, we have projected approximate time transects through the Upper Ordovician strata on the basis of rock relations. Thin lithostratigraphic units are assumed to be practically synchronous, although the time of deposition even of thin limestone or mudstone units probably differed from place to place. Examples of thin rock units here considered to be nearly time parallel are the Back Bed of the Tate Member of the Ashlock Formation and the Terrill, Sunset, and Reba Members of the Ashlock (pl. 7). Intertonguing and intergrading of several units indicates their partial contemporaneity—for example, the Garrard Siltstone with the Clays Ferry Formation (pl. 6) and the Tate Member of the Ashlock with the Grant Lake Limestone (pl. 7). In the absence of clearer lithologic evidence of time relations, we have drawn time transects through relatively thick rock units, such as the Bull Fork Formation, on the basis of relative thickness, parallel where possible to thin lithostratigraphic units elsewhere in the section. Thus, the time transects used to illustrate the distribution of lithofacies during the Late Ordovician are perforce generalized. The time terms used here are informal and approximate.

Pictures of the paleogeography of central Kentucky throughout the time of deposition of the Lexington Limestone were presented by Cressman (1973c, p. 54-55, pl. 9). During early Lexington time, the area was a shelf that sloped gently northward and was covered by marine waters of shallow to moderate depths. During late Lexington time, the chief feature of central Kentucky was a topographic high, the Tanglewood bank of Hrabar and others (1971), which trended west-northwest across the central part of the area. The extent and width of this bank varied in response to minor changes in sea level. Calcitic silt and shale were laid down in the deeper waters flanking the high. Calcarenite formed a shelf-edge sand and at times spread over much of the bank. Deposition of the Lexington Limestone was ended by a major transgression during which the shale, limestone, and siltstone beds of the Clays Ferry Formation were laid down.

A transect through the post-Lexington strata (fig. 61) shows the distribution of facies in middle Clays Ferry time. Only two lithofacies, both belonging to group I, were present. The presence of even-bedded fossiliferous limestone and shale of lithofacies B throughout most of the southern and central parts of the area suggests that most of the shelf was of moderate depth. Shale and fossiliferous limestone of lithofacies D, suggestive of somewhat deeper waters, covered the northern part of the State. These relations imply a return to the gentle northward slope of the shelf, characteristic of this area during early Lexington time. This pattern of lithofacies persisted, with minor variations, throughout most of the time of deposition of the Clays Ferry and Kope Formations, but in the later part of this period, siltstone of lithofacies J forming the Garrard Siltstone was deposited in the eastern and south-central parts of the study area (fig. 16). The distribution of lithofacies J suggests that its land-derived silt was supplied from a distant southeastern source.

Lithofacies present in middle Fairview time (fig. 62) were still dominantly of group I. Even-bedded fossiliferous limestone and shale of lithofacies B retreated northeastward, and lithofacies A, thin-bedded fossiliferous limestone, occupied the central part of the area. A member of group II, nodular-bedded fossiliferous limestone and shale of lithofacies E, covered the southern part of the area. This distribution of lithofacies shows a general southward increase in the energy of the depositional environments and reflects a southward shallowing of the sea. The deepest parts of the shelf were on the north and northeast.

By middle Grant Lake time (fig. 63) the lithofacies were more diverse, and representatives of groups I, II, and IV each occupied about a third of the study area. Group I, represented by even-bedded fossiliferous shale and limestone of lithofacies C, occupied the northern part of Kentucky in a pattern similar to that of the shale and fossiliferous limestone of lithofacies D in middle Clays Ferry time (fig. 61). Group II lithofacies occupied the central part of the area. A belt of nodular-bedded limestone and shale of lithofacies E, which previously lay south of approximately the latitude of Stanford, now lay much farther north. In the northwestern part of this belt, near Bedford, Ky., local shoaling is evidenced by an elliptical area of nodular-bedded limestone and calcarenite of lithofacies F. Group IV lithofacies covered the southern part of the study area. A belt of dolomitic mudstone of lithofacies K was succeeded south of Stanford by a belt of dolomite and calcitic dolomite of lithofacies M. These group IV lithofacies are virtually unfossiliferous and probably were deposited in penesaline intratidal and supratidal environments that became generally harsher southward. Middle Grant Lake time was thus a period of considerable regression in the late Ordovician.

Conditions in Kentucky were not much changed in middle Gilbert time (fig. 64). The distribution of lithofacies M was about the same as previously. The distribution of the calcarenite and nodular-bedded limestone of lithofacies F shows that the shoals near Bedford contracted and that similar small areas of shoaling appeared south of Maysville and northeast of Mount Sterling. Micrograined limestone of lithofacies I replaced the belt of lithofacies K, dolomitic mudstone, south of the latitude of Bardstown. This change reflects a transition to relatively clear water lagoonal conditions and a decreasing supply of land-derived silt and clay.

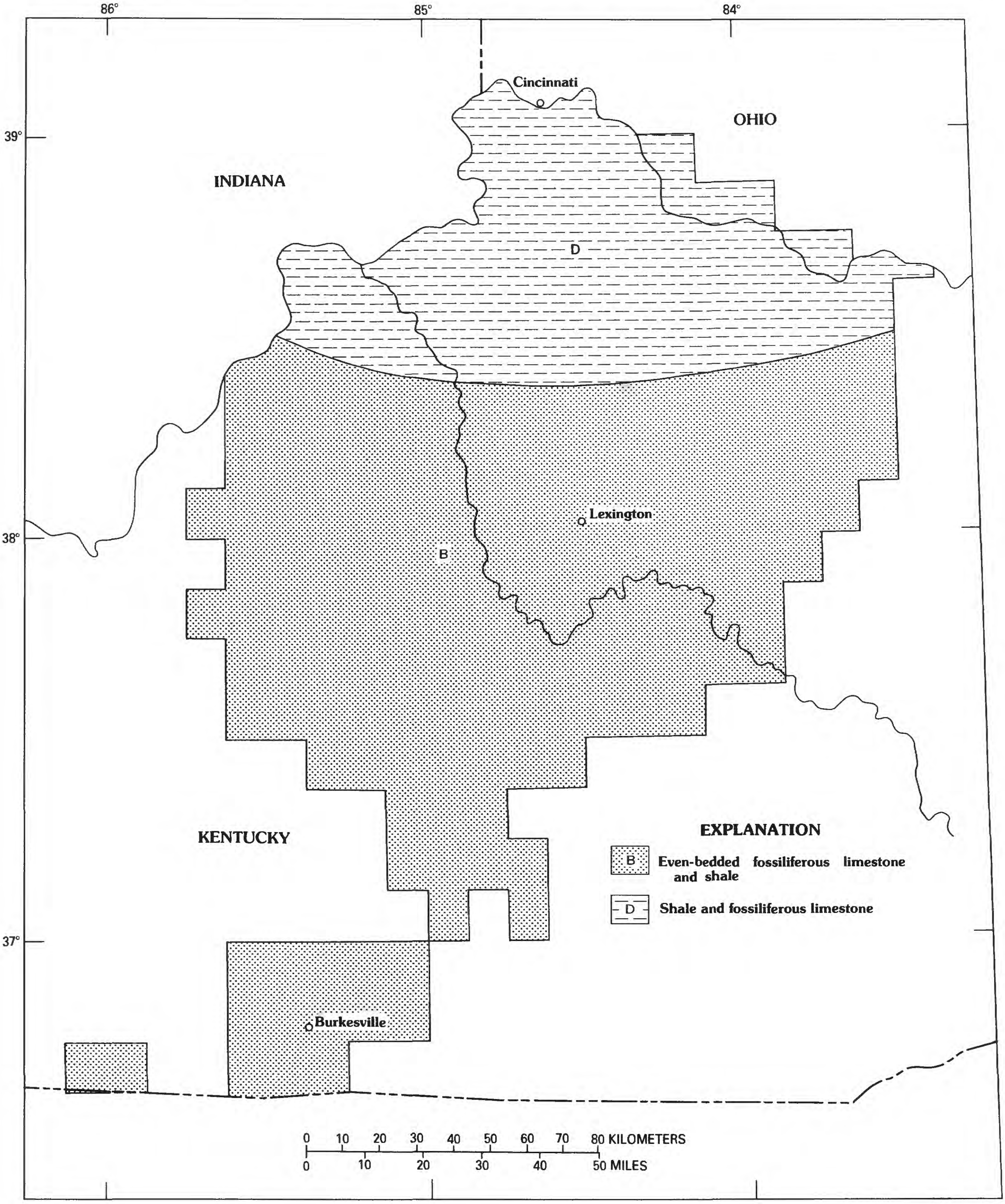

FIGURE 61.—Part of Kentucky, showing distribution of lithofacies in middle Clays Ferry time.

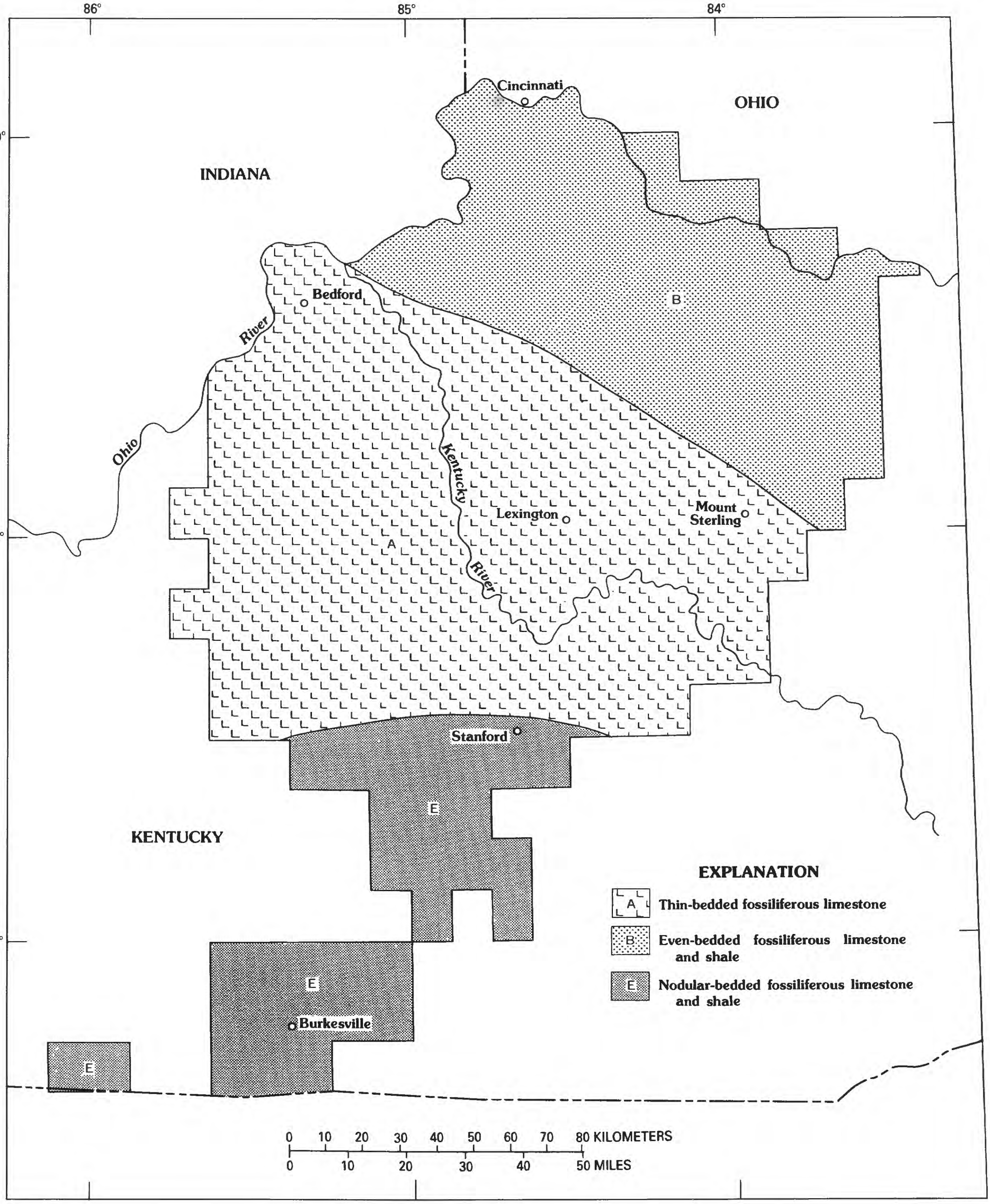

FIGURE 62.—Part of Kentucky, showing distribution of lithofacies in middle Fairview time.

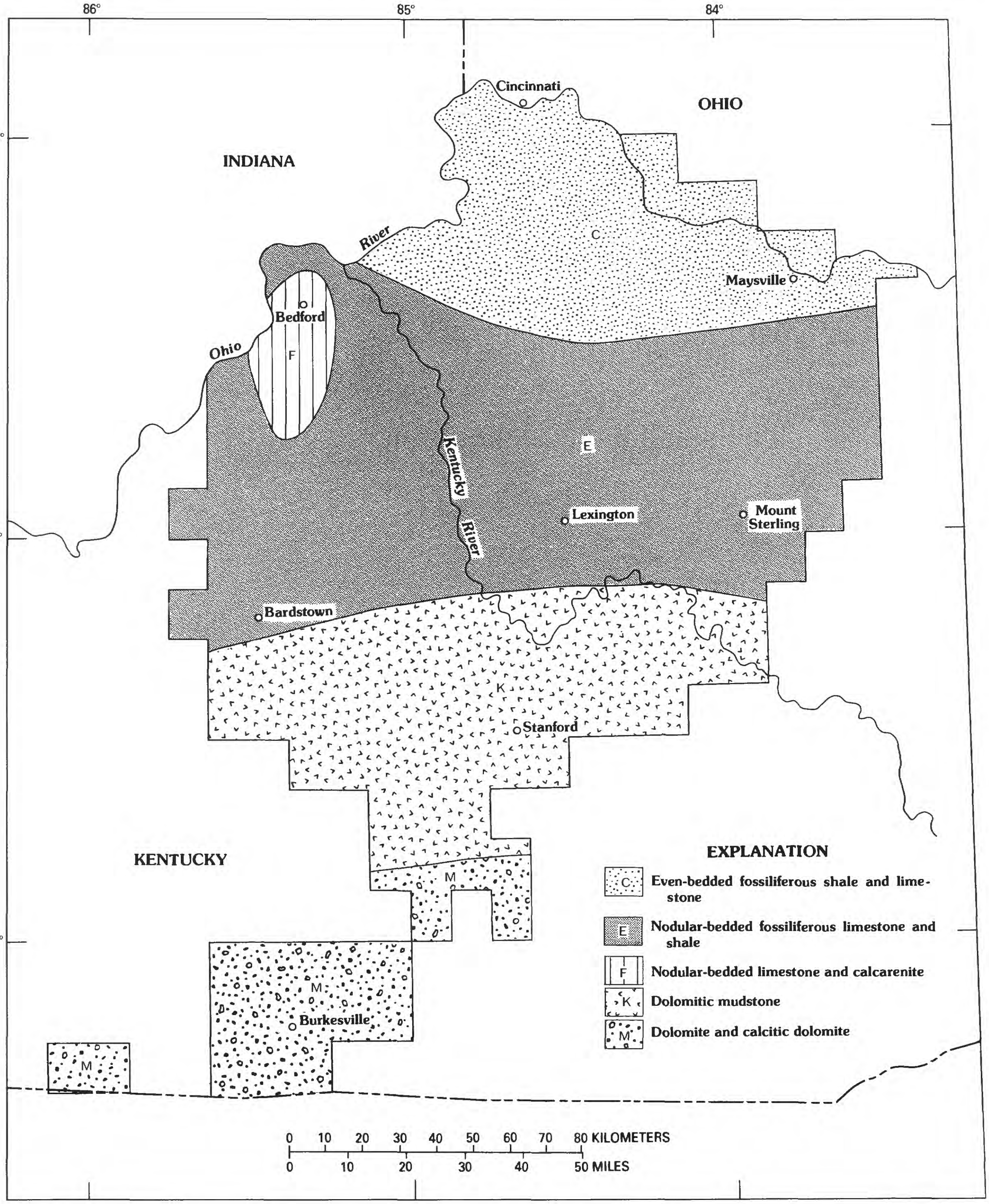

FIGURE 63.—Part of Kentucky, showing distribution of lithofacies in middle Grant Lake time.

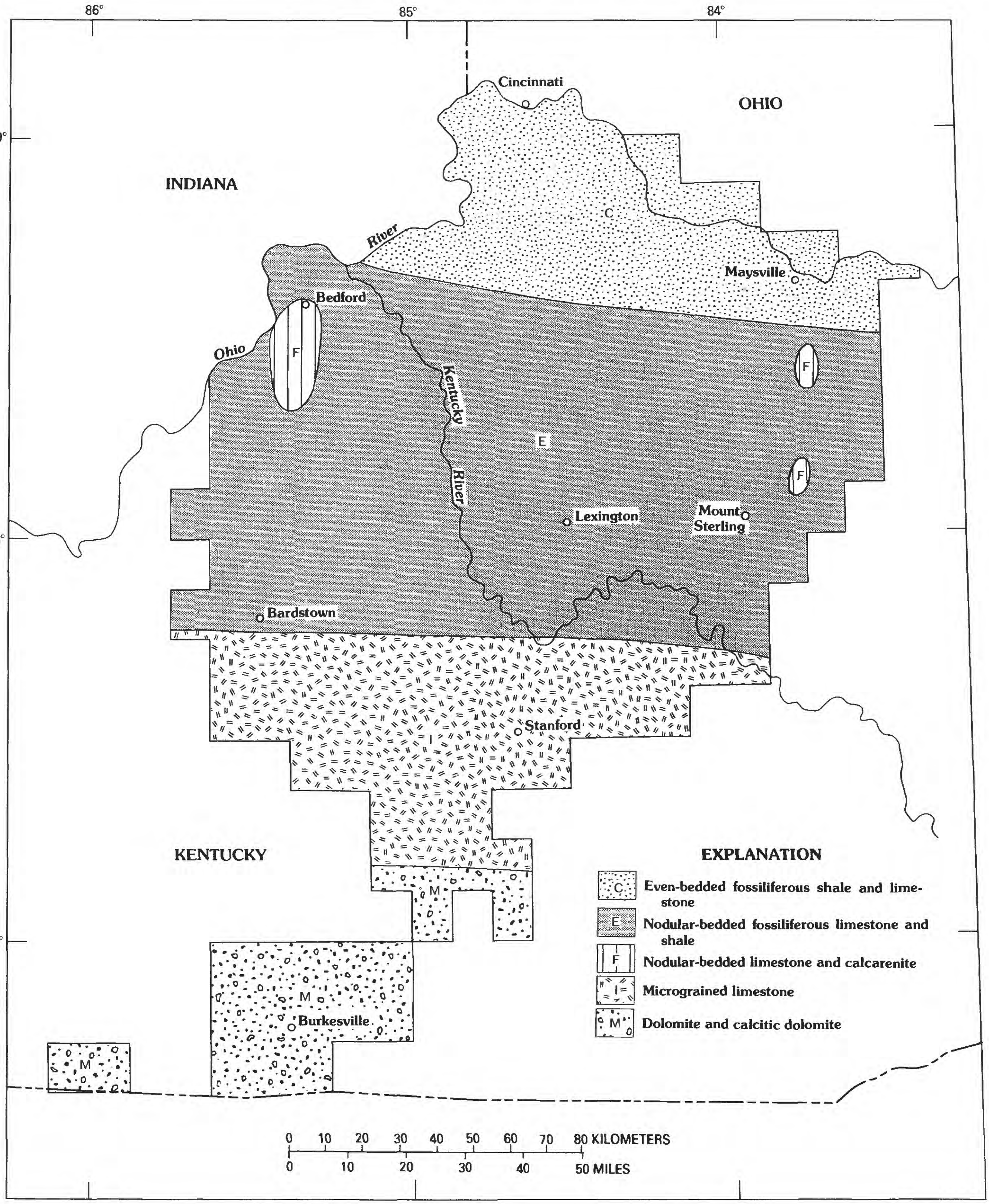

FIGURE 64.—Part of Kentucky, showing distribution of lithofacies in middle Gilbert time.

The pattern of lithofacies in middle Bull Fork time (fig. 65) reflects a southward transgression of the Late Ordovician sea. The boundaries of group I and II lithofacies were shifted southward relative to their position in middle Gilbert time. Nodular-bedded mudstone of lithofacies G occupying the southeastern part of the belt of group II lithofacies possibly reflects a supply of clay and silt from the distant southeastern lands that earlier supplied sediment for the Garrard Siltstone. Lagoonal micrograined limestone of lithofacies I was no longer present and was replaced on the southeast by intertidal and supratidal dolomitic mudstone of lithofacies K.

Middle Rowland time (fig. 66) was a period of regression. Group II lithofacies were no longer present, and the boundary of group IV lithofacies was farther north than previously. Dolomitic limestone and mudstone of lithofacies N, present only in this interval, covered the shoaling area indicated by calcarenite of lithofacies F in middle Grand Lake time. Lithofacies N represents a shallow subtidal environment allied to the periodically hypersaline subtidal environments of lithofacies K to the south but transitional with the shallow open marine environments of lithofacies C on the north and east.

Shortly after middle Rowland time, a minor unit, the calcarenite and calcirudite of the Marble Hill Bed of the Rowland Member of the Drakes Formation, was deposited along and near the northwestern pinchout of the Rowland (fig. 39). Limestone of the Marble Hill, a complex of offshore-bar and tidal-channel deposits (Swadley, 1979), was laid down in a narrow belt near the seaward edge of the shallow marine platform on which was deposited lithofacies N (fine-grained limestone and calcitic mudstone of the Rowland Member). Lithofacies C (even-bedded fossiliferous shale and limestone of the Bull Fork Formation and of the Bardstown Member of the Drakes Formation) here lies below, laterally adjacent to, and above lithofacies N, which constitutes the northwestern part of the Rowland (fig. 40). The Marble Hill Bed was formed from carbonate sand built up in a high-energy environment on the platform edge, where the wave base impinged on the sea floor as it shoaled from the open shelf to shallower, more restricted waters indicated by lithofacies N (Swadley, 1979).

Middle Bardstown time (fig. 67) included the last significant transgression in the study area during the Late Ordovician. The even-bedded fossiliferous shale and limestone of lithofacies C that make up the Bardstown Member spread over and extended south of the area previously occupied by lithofacies N (calcitic rock of the Rowland Member). During this time, a northeastward trend of the boundary between open marine environments (indicated by lithofacies C) and more restricted subtidal and supratidal environments (indicated by the dolomitic mudstone and dolomite of lithofacies L) became evident. This trend suggests a northwestward shift in the direction of slope of the shelf; it may also reflect the supply of clay and silt to lithofacies L from distant southeastern lands. The southern part of the study area continued to be characterized by restricted subtidal and supratidal environments, as indicated by the dolomite and calcitic dolomite of lithofacies M.

By middle Saluda time (fig. 68), only lithofacies of group IV were present in the study area. The close of the Late Ordovician was here a time of great regression. The northerly trend of the boundary between dolomite and calcitic dolomite of lithofacies M and the dolomitic mudstone and dolomite of lithofacies L may have resulted from the influx of clay and silt into lithofacies L from distant eastern sources.

In summary, the post-Lexington strata cropping out in Kentucky were deposited on a shelf that sloped generally northward. Shale, limestone, and siltstone were the initial deposits in open marine waters of moderate depth on this shelf. Later, as the seas shallowed, the northern part of the shelf was mostly covered by fossiliferous limestone and shale, and the southern part by dolomitic mudstone and dolomite. Near the close of the Late Ordovician, the seas withdrew northward, and the entire area was covered by dolomitic mudstone and dolomite.

SEDIMENTATION AND STRUCTURE

Sedimentation during the Late Ordovician in the study area does not appear to have been controlled by the major structural elements recognized in central Kentucky (fig. 6). Such control has been noted elsewhere in the region during the early Paleozoic. For example, uplift along the Cincinnati arch affected deposition of Middle Ordovician and Devonian rocks in central Tennessee (Wilson, 1949, p. 328-333; Wilson and Stearns, 1963, p. 825-829) and Silurian and Devonian rocks in central Kentucky (McFarlan, 1939). Also, movement along normal faults in the study area, as in the Kentucky River and Irvine-Paint Creek fault zones, possibly influenced sedimentation of the Lexington Limestone (Cressman, 1973c, p. 55; Osborne and Borella, 1976; Borella and Osborne, 1978).

Upper Ordovician rocks in the study area have been removed by erosion from much of the axial region of the Cincinnati arch, and so details of the lithologic relations to this structure are uncertain. Where the Upper Ordovician strata do cross the approximately north-south trending axis of the arch in north-central and southern Kentucky, the lithofacies show little or no change.

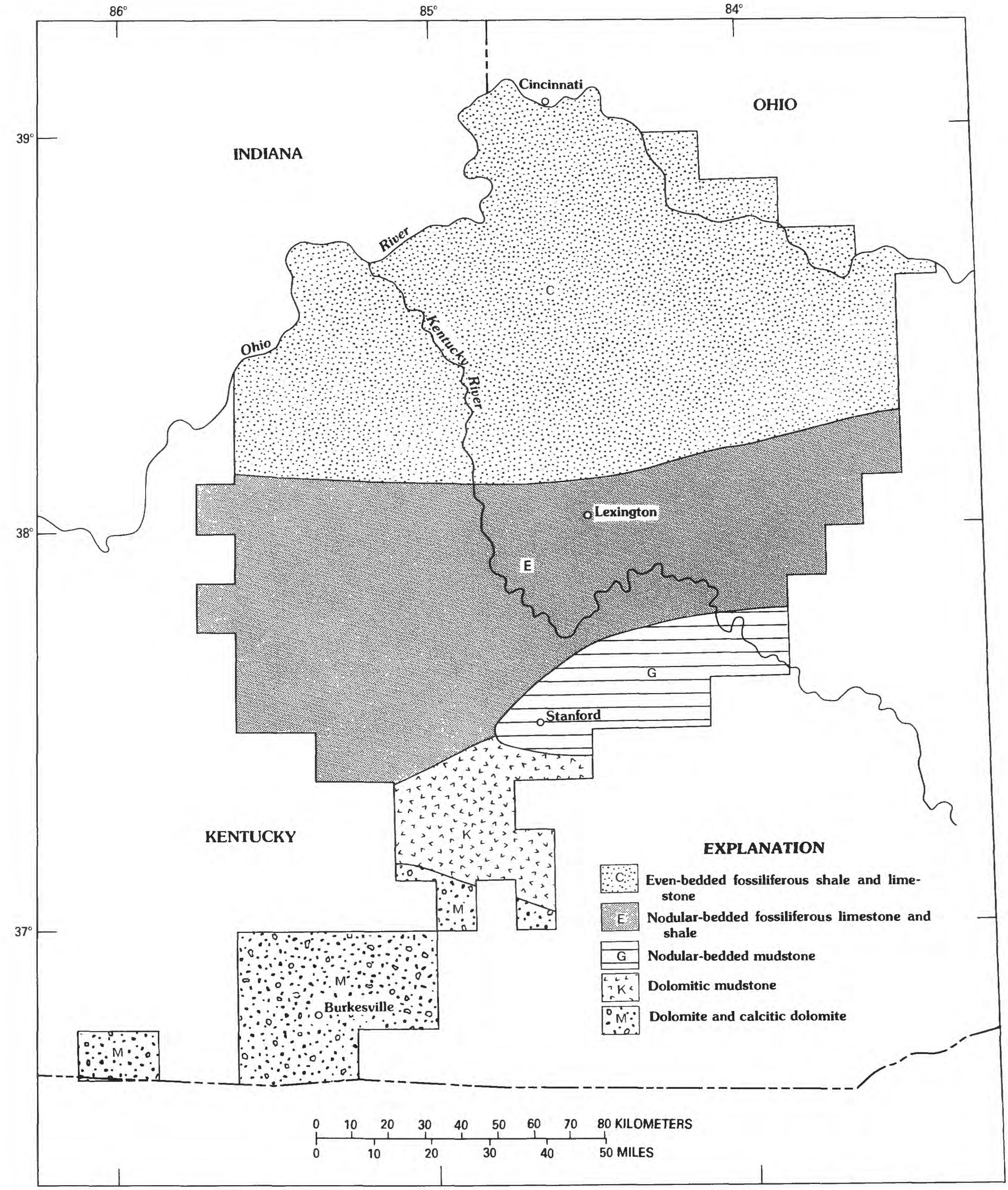

FIGURE 65.—Part of Kentucky, showing distribution of lithofacies in middle Bull Fork time.

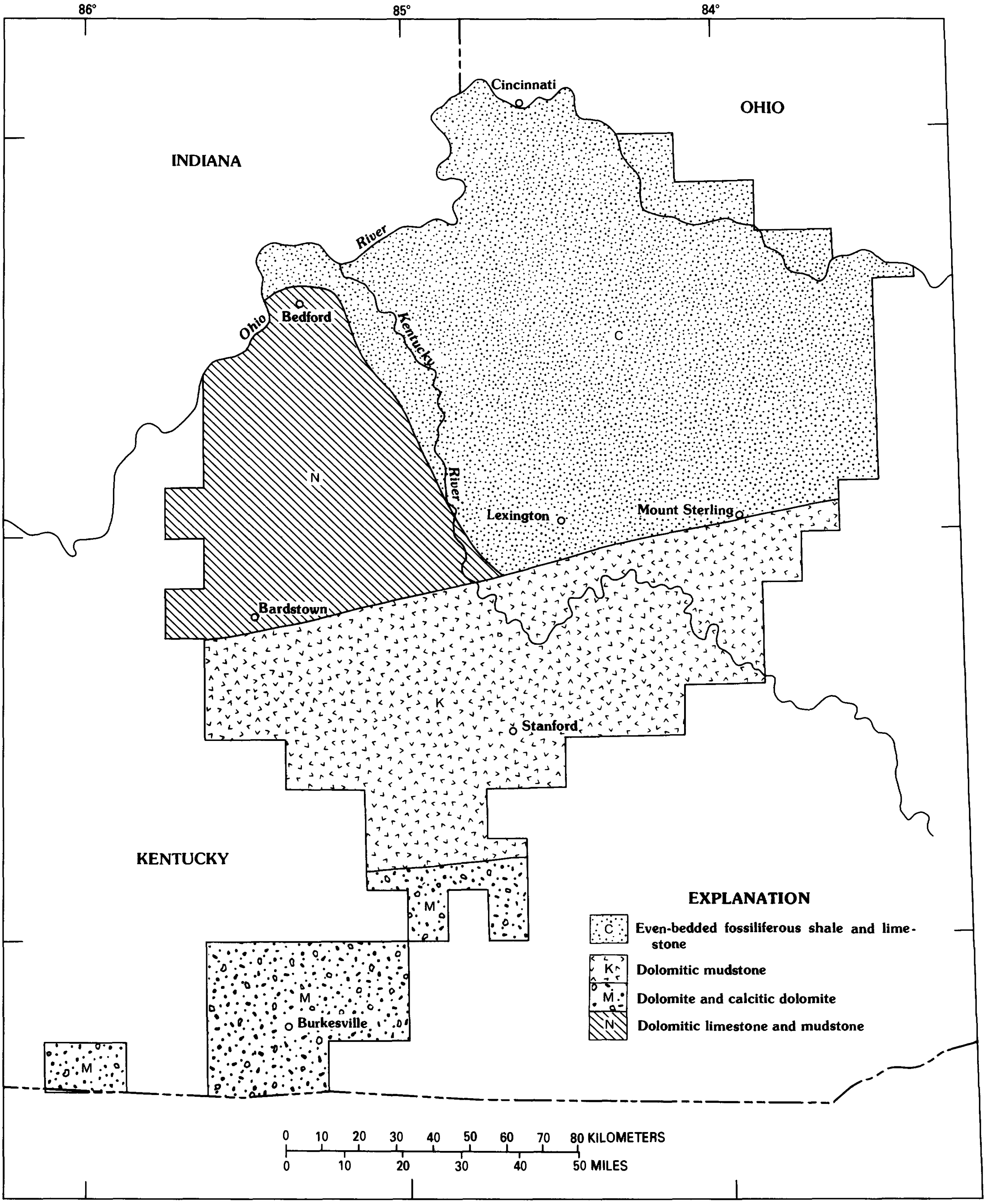

FIGURE 66.—Part of Kentucky, showing distribution of lithofacies in middle Rowland time.

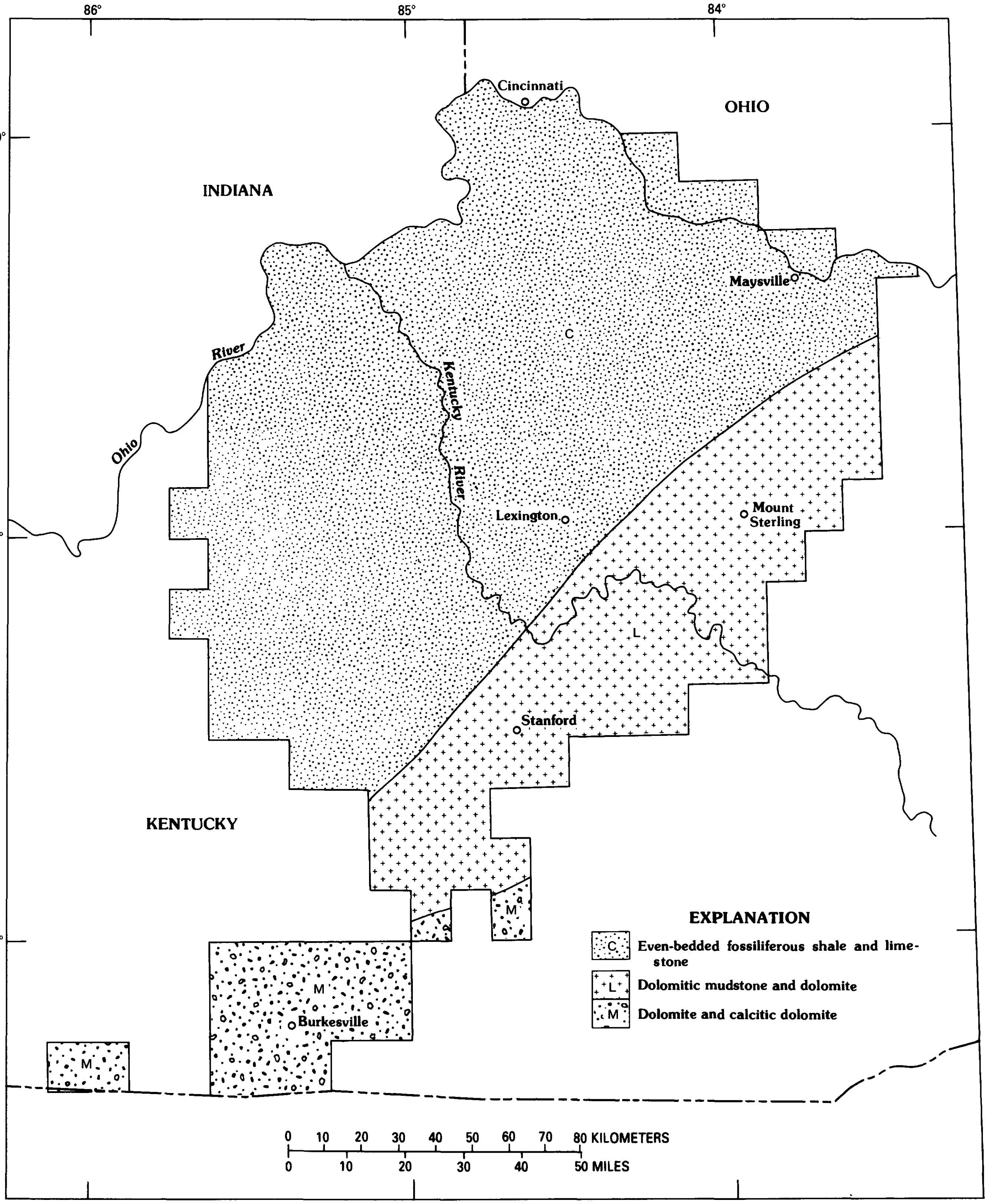

FIGURE 67.—Part of Kentucky, showing distribution of lithofacies in middle Bardstown time.

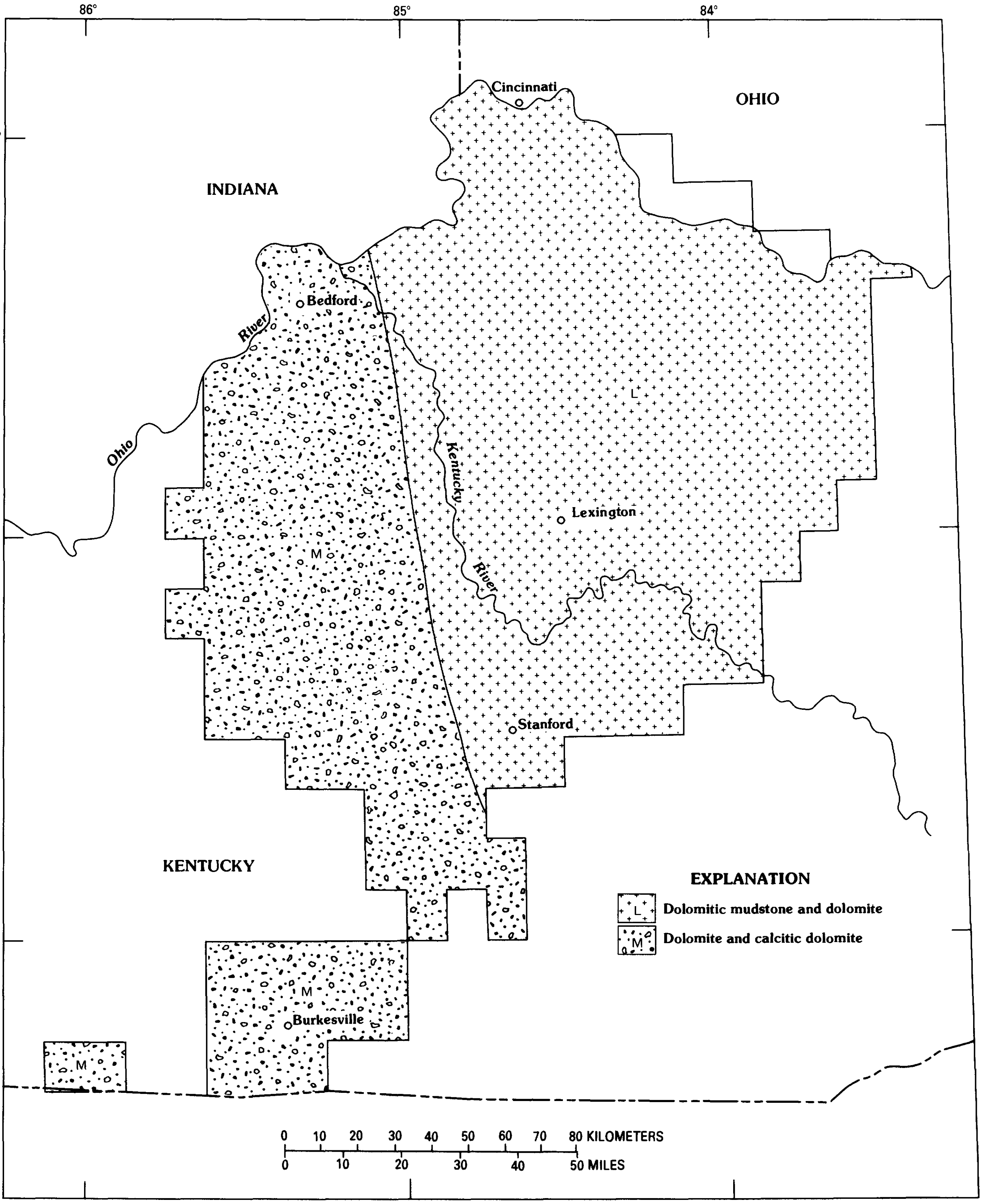

FIGURE 68.—Part of Kentucky, showing distribution of lithofacies in middle Saluda time.

Reasonable projections of areas of distribution and contours of thickness of lithofacies generally trend transverse to the axis of the arch. In the few places where the lithofacies boundaries parallel the arch, the parallelism may be explained by the regional slope of the shelf. Thus, the approximately north-south trending boundary between lithofacies L and M (the Preachersville and Saluda Dolomite Members of the Drakes Formation; see fig. 68) is probably related to an eastern supply of terrestrial clay and silt and a westward shallowing of the sea.

Many of the Upper Ordovician lithofacies through time (figs. 61-68) trend nearly east-west, approximately paralleling several major faults: The Brumfield fault, the Kentucky River fault zone, and the Irvine-Paint Creek fault zone (fig. 6). This parallelism suggests that tilting of crustal blocks along these faults, some of which are known to have been active during the Cambrian (Webb, 1969), influenced sedimentation patterns during the Late Ordovician. Geographic correspondence between changes in lithofacies and the major faults, however, is not close. Most lithofacies changes along the eastern belt of outcrop in the study area (cross sec. *B-B′*, pl. 7) are near Mount Sterling, north of the fault zones, and near Richmond, south of the fault zones. Along the western belt of outcrop (cross sec. *C-C′*, pl. 7), the areas of greatest change in the lithofacies are mostly near Bedford and Bardstown, far from major faults.

REGIONAL RELATIONS

Figure 69 shows the generalized lithofacies relations and inferred paleogeography in part of the Eastern United States during the late Cincinnatian, on the basis of our interpretations of data from the recent geologic literature. Particularly helpful were papers describing the Ordovician stratigraphy of large regions: North America (Clark and Stearn,1968, p.145-149; Cook and Bally, 1975), the Eastern United States (Dennison, 1976; Neuman, 1976), and the Western United States (Ross, 1976).

The Late Ordovician latitudes shown on figure 69 are drawn from Ross (1976, fig. 1c, p. 75), who interpolated between the latitudinal positions based on paleomagnetic poles determined by McElhinny and Opdyke (1973, table 4, p. 3704) for the earliest Cincinnatian and Early Silurian. The Late Ordovician paleoposition of the Eastern United States in tropical latitudes is consistent with the paleoclimatic zones inferred from regional distributions of fossils and rock types (Spjeldnaes, 1961, fig. 5A, p. 66; Dott and Batten, 1971, p. 242). Low latitudes are especially favorable for the production of carbonate shells (Fairbridge, 1967, p. 404) and are consonant with the richly fossiliferous limestone and calcitic shale that characterize much of the Cincinnatian strata in the Eastern United States.

During the Late Ordovician, an epeiric sea occupied most of the eastern interior of the United States; the sea shelved generally eastward to lands along the margin of the continent. The miogeosyncline lying near the eastern borderlands during Lexington time (Cressman, 1973c, pl. 11) had been effaced, probably in part by infilling with land-derived sediment.

In the northeastern part of the map area of figure 69, highlands that were formed during the Ordovician by the Taconic orogeny shed coarse to fine detritus westward onto the continental platform. This depositional system is recorded in New York and adjoining States to the west and southwest by lower delta-plain deposits of the Queenston Shale, which is composed chiefly of red and green shale, although in central New York it includes siltstone and sandstone (Fisher, 1977, p. 21). The terrestrial deposits of the Queenston apparently intergrade as tidal and subtidal deposits in the subsurface of central Ohio with marine deposits much like the fossiliferous limestone and calcitic shale of the Bull Fork Formation. The shape and distribution of lands in the southern part of the map area is uncertain because later events have obscured effects of the Taconic orogeny. The presence of southeastern highlands, however, is attested in West Virginia and adjoining States by fine- to coarse-grained alluvial red beds of the Juniata Formation and its analogs deposited along the landward margin of the shelf.

West of the Juniata is a broad area, mostly in Kentucky and Tennessee, of dolomitic rocks, ranging in composition from dolomite to dolomitic limestone and dolomitic mudstone and including some limestone and calcitic shale. The dolomitic assemblage was laid down on the shallowest part of the shelf and consists chiefly of supratidal and tidal deposits. Dennison (1976, p. 115) ascribed the red beds in these and other deposits marginal to the Late Ordovician seas to a eustatic lowering of sea level related to Ordovician glaciation in North Africa. This glacioeustatic lowering permitted red terrestial sediment to be carried farther out on the shelf and exposed marine mud to be oxidized red as a result of subaerial weathering.

The dolomitic lithofacies grades generally northward into fossiliferous limestone and shale within the study area (pl. 7; figs. 65-67). Similar relations in the Late Ordovician of southeastern Tennessee between red and green dolomitic limestone of the Sequatchie Formation and gray richly fossiliferous limestone of the Shellmound Formation were described by Milici and Wedow (1977). Limestone lithofacies were dominant on the shelf in the central part of the map area of figure 69.

Variations in bottom relief and consequent variations in water temperature, circulation, and turbulence resulted in areal lithologic and faunal differences in the fossiliferous limestone assemblage.

In the western part of the region, Upper Ordovician outcrops are less common, but broad studies, based partly on analyses of subsurface data (Templeton and Willman, 1963; Gray, 1972), indicate that shale becomes dominant over limestone. This increase in the abundance of shale probably reflects a deepening of the shelf and consequently quieter waters in which the shale-forming particles could settle out. At the west edge of the map area (fig. 69) was a relatively positive area at the site of the present-day Ozarks; Ordovician seas may never have covered all of this upland (Freeman, 1953, p. 24). Clastic rocks and unconformities are evidence of repeated uplifts during the Middle Ordovician (Templeton and Willman, 1963, p. 136-137). The Ozark dome was probably a low positive element at times during the Late Ordovician, because rocks of this age thin and become more coarsely clastic toward the dome (Gutstadt, 1958, p. 540). Regional shallowing of the Cincinnatian sea accompanying uplift of the dome near the close of the Middle Ordovician effaced the ancestral Mississippian embayment inferred by Cressman (1973c). During late Cincinnatian time, the Ozark uplift may have extended southeastward into western Tennessee (Wilson, 1949, p. 331). The end of the Cincinnatian epoch in the region was marked by a general lowering of sea level and local withdrawal of the epeiric sea.

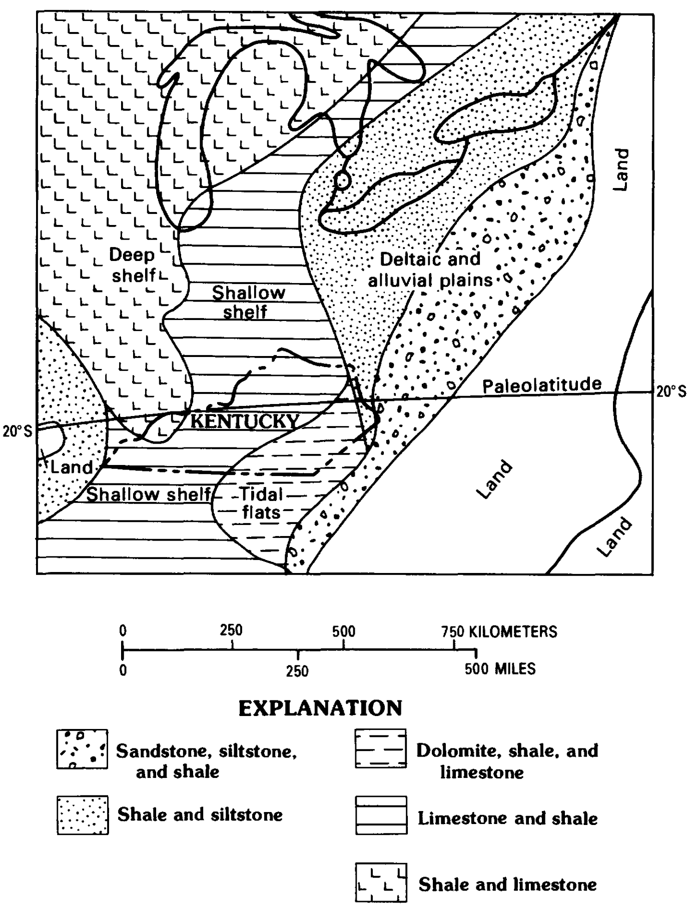

FIGURE 69.—Part of Eastern United States, showing dominant rock types and inferred depositional environments in late Cincinnatian time.

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GPO 587-044/10018