Stratigraphy of the Silurian Outcrop Belt on the East Side of the Cincinnati Arch in Kentucky, With Revisions in the Nomenclature

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1151–F

Prepared in cooperation with the Kentucky Geological Survey

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By ROBERT C. McDOWELL

CONTRIBUTIONS TO THE GEOLOGY OF KENTUCKY

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A description of the lithology and distribution of sedimentary formations of Early and Middle Silurian age, with revisions in stratigraphic nomenclature

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STRATIGRAPHY OF THE SILURIAN OUTCROP BELT ON THE EAST SIDE OF THE CINCINNATI ARCH IN KENTUCKY, WITH REVISIONS IN THE NOMENCLATURE

By ROBERT C. MCDOWELL

ABSTRACT

Silurian rocks form a narrow arcuate outcrop belt about 100 mi long on the east side of the Cincinnati Arch in Kentucky. They range from as much as 300 ft thick in the north to a pinchout edge in the south. The nomenclature of this sequence is revised to reflect mappability and lithologic uniformity on the basis of detailed mapping at a scale of 1:24,000 by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey. The Silurian rocks are divided into two parts: the Crab Orchard Group, raised in rank from Crab Orchard Formation and redefined, in the lower part of the Silurian section, and Bisher Dolomite in the upper part of the section. The Crab Orchard Group is subdivided into the Drowning Creek Formation (new name) at the base of the Silurian, overlain by the Alger Shale (adopted herein) south of Fleming County and by the Estill Shale (elevated to formational rank) north of Bath County. The Brassfield Member (reduced in rank from Brassfield Dolomite or Formation) and the Plum Creek Shale and Oldham Members of the former Crab Orchard Formation are included as members of the Drowning Creek; the Lulbegrud Shale, Waco, and Estill Shale Members of the former Crab Orchard Formation are now included in the Alger.

The Drowning Creek Formation, 20 to 50 ft thick, is composed mainly of gray fine- to coarse-grained dolomite with shale interbeds. The dolomite beds average several inches thick, with bedding surfaces that are locally smooth but generally irregular and are fossiliferous in many places; fossils include brachiopods, crinoid columnals, horn corals, colonial corals, trilobites, pelecypods, and bryozoans. The shale interbeds average several inches thick, except for its Plum Creek Shale Member which is entirely shale and as much as 12 ft thick, and are most abundant in the upper half of the formation. The members of the Drowning Creek intergrade and are indistinguishable in the northern part of the area.

The Alger Shale, as much as 170 feet thick, is predominantly grayish-green clay shale with a thin (0.5–3 ft) dolomite member (the Waco, or its northern equivalent, the Dayton Dolomite Member, reduced in rank from Dayton Limestone) near the base. North of Bath County, the Lulbegrud Shale and Dayton Dolomite Members are reassigned to the underlying Drowning Creek Formation, the Estill Shale Member is elevated to formational status, and the Alger is dropped.

The Bisher Dolomite, which overlies the Estill Shale in the northernmost part of the Silurian belt, ranges from 0 to 300 ft in thickness and is composed of medium-to coarse-grained, gray, fossiliferous dolomite.

The Silurian section overlies Upper Ordovician rocks in apparent conformity, although faunal studies suggest a minor hiatus, and is overlain by Middle to Upper Devonian rocks in a regional angular unconformity that truncates the entire Silurian section at the southwest end of the outcrop belt, where it is nearest the axis of the Cincinnati Arch. All of the units recognized in the Silurian appear to thicken eastward, away from the axis of the arch and towards the Appalachian basin. This, with the presence of isolated remnants of the Brassfield near the axis, suggest that formation of the arch was initiated in Early Silurian time by subsidence of its eastern flank.

INTRODUCTION

Silurian rocks east of the axis of the Cincinnati Arch in Kentucky form a narrow arcuate outcrop belt about 100 mi long extending from Lewis County, on the Ohio River, southward and southwestward to Lincoln County in south-central Kentucky (figs. 1, 2). From outcrop, the Silurian extends eastward and thickens in the subsurface; westward, it has been removed from the crest of the arch and is overstepped by Devonian rocks along a major unconformity, leaving only a few small, isolated outcrop areas to the south and west of the main outcrop belt. The Silurian rocks of east-central Kentucky comprise mostly dolomites and shales, with some limestones, of Early and Middle Silurian age. This report describes the stratigraphic relationships of these Silurian rocks as determined by recent geologic mapping at a scale of 1:24,000 by the U.S. Geological Survey (USGS) in cooperation with the Kentucky Geological Survey (KGS). A similar report, discussing the Silurian outcrop on the west side of the arch, has been published recently by Peterson (1981).

A total of 44 geologic maps (covering all or parts of 45 quadrangles) that include the Silurian rocks exposed east of the arch were produced during the mapping program by 23 authors, with publication beginning in 1964 and continuing through 1978 (fig. 2). In addition

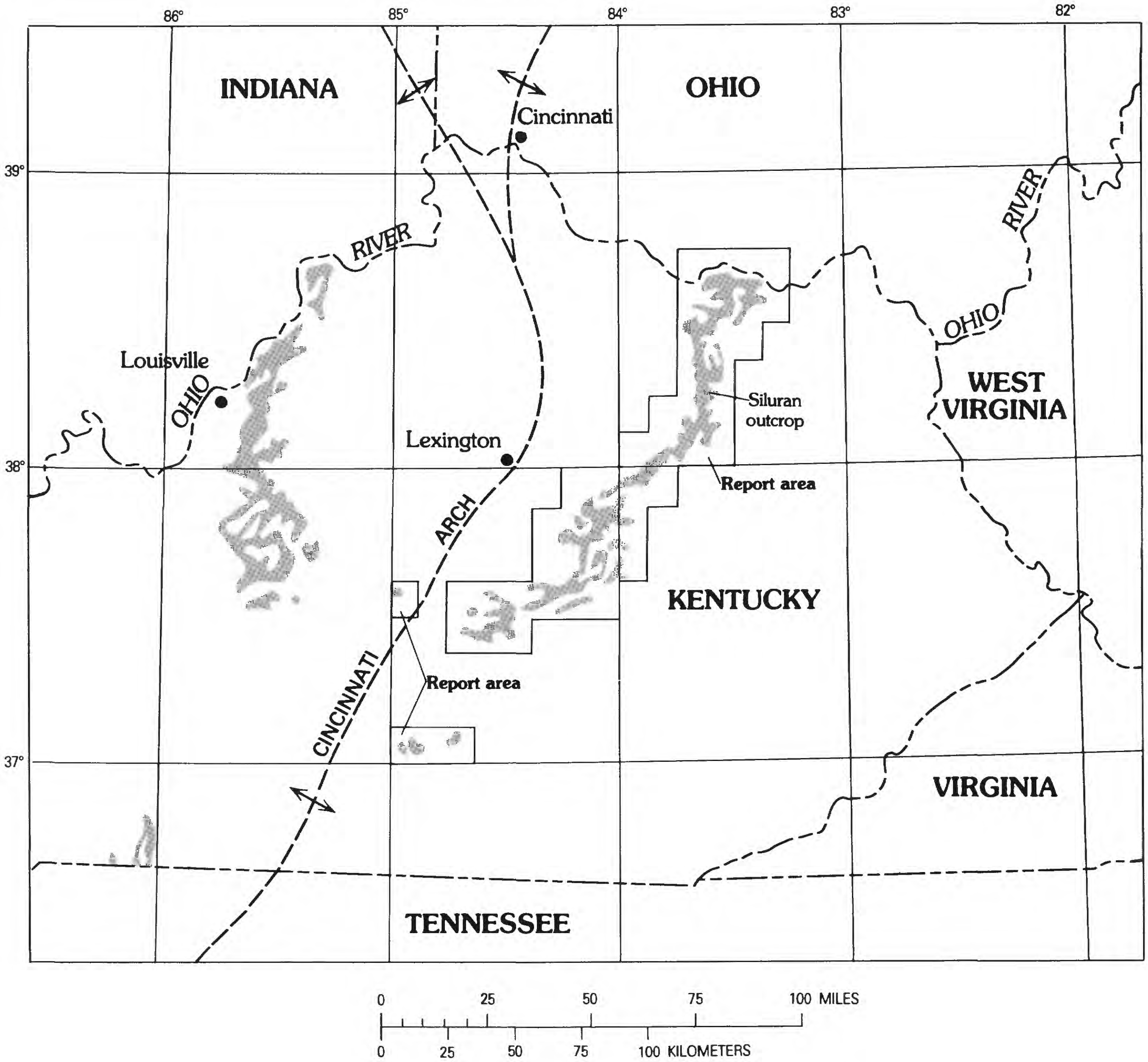

FIGURE 1.—Area of outcrop of Silurian rocks in Kentucky (shaded), location of area studied, and the approximate position of the axis of the Cincinnati Arch.

to the geologic mapping, these rocks were studied by detailed measurement of numerous sections, by rapid-rock chemical analyses in USGS laboratories, and by thin-section examination. Petrology of the shales from a drill core was studied by Harry A. Tourtelot. Conodonts collected during the mapping program were reexamined and identified for this report by Anita G. Harris. Edward O'Donnell made available a large collection of notes, hand specimens, and thin sections.

Many of the stratigraphic sections used in this study were measured by George W. Simmons, John H. Peck, G. W. Weir, J. C. Gualtieri, R. C. Greene, D. R. Seigle, P. C. Cassity, R. H. Morris, and F. A. Schilling, Jr. In particular, the extensive notes, diagrams, and written comments of Simmons and Peck were invaluable in the preparation of this report.

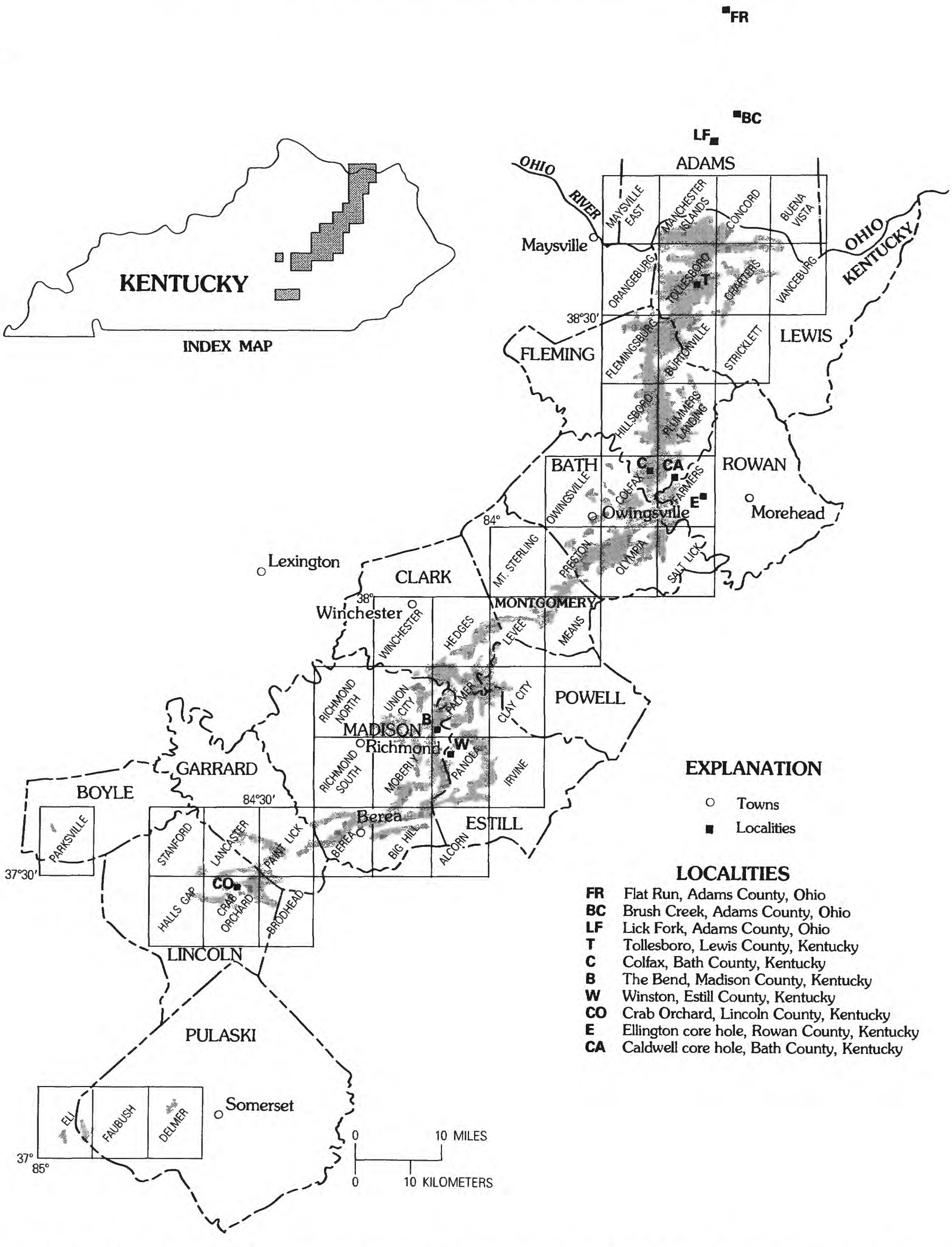

FIGURE 2.—The Silurian outcrop belt, east-central Kentucky. Silurian outcrop area (shaded), counties, 7½-min quadrangles, principal towns, and localities mentioned in the text. Outcrop area from the Geologic Map of Kentucky (McDowell and others, 1981).

STRATIGRAPHY

General Statement

In Kentucky, Silurian rocks cropping out east of the Cincinnati Arch can be generalized as a sequence of dolomite and shale as much as 300 ft thick (but much thinner in most of the area); dolomite is predominant at the bottom and top of the section, with shale between. This sequence, which is truncated everywhere by a major regional unconformity at the base of the overlying Devonian rocks, is divided into four formations (fig. 3), of which three are established in this report. Two of these formations are further subdivided into seven members which, despite being relatively thin, can be recognized over most of the area. Most of these units were originally recognized by A. F. Foerste (1906), who was the first to study the Silurian rocks in this region in detail. His pioneering work, extending over a 40-yr period, remains the basis for the classification and understanding of these rocks.

The evolution of the nomenclature of the Silurian rocks east of the Cincinnati Arch is shown in fig. 4 As shown in the figure, the pre-Bisher Silurian was divided into two formations for use in the USGS–KGS mapping program, the Crab Orchard Formation and the Brassfield Dolomite (Formation). On the basis of knowledge gained as a result of the mapping program, and discussed in the following sections, these formations are redefined in this report and a modified nomenclature is set up. No changes are made in the definition of Bisher Dolomite, which is limited in occurrence to a small area at the north end of the Silurian outcrop belt, mostly in Lewis County.

The Silurian rocks in this outcrop belt are truncated by a regionally extensive erosion surface and are overlain, probably with a slight angular discordance, by rocks of Middle to Late Devonian age. These include the Boyle Dolomite in most of the southern and central part of the belt and the Ohio (New Albany, Chattanooga) Shale elsewhere. Traditionally, carbonate rocks occurring beneath this thick, black, carbonaceous shale have been referred to by oil drillers as the "Corniferous," which can thus refer to either the Middle Devonian Boyle Dolomite or the Lower to Middle Silurian dolomites (Freeman, 1951, p. 23–26).

Crab Orchard Group

The rocks from the base of the Silurian up to the base of the Bisher Dolomite constitute a gradational, continuous sequence of interbedded dolomite and shale (fig. 3). The combination of this section into a single stratigraphic unit serves to distinguish it stratigraphically from the dissimilar lithologies above and below and to emphasize its genetic continuity. Accordingly, the name Crab Orchard, previously used as a formational name, is expanded and redefined herein as the Crab Orchard Group, to include all Silurian rocks below the Bisher Dolomite in Kentucky east of the Cincinnati Arch. The group contains three formations: the Drowning Creek Formation below and the Alger and Estill Shales above, which are introduced herein to replace the Brassfield Dolomite (Formation) and Crab Orchard Formation as used in the USGS–KGS mapping program. The name, Crab Orchard, was originally proposed by Linney (1882) for a "group of clay shales" that lay above the "Medina sandstone" (Brassfield Dolomite Formation) and below Devonian rocks in Lincoln County, Kentucky. Foerste (1906, p. 62–63) later raised the unit to "Crab Orchard Division," which included his Alger and Indian Fields formations. The name comes from the town of Crab Orchard in Lincoln County; no type section was designated by Linney or Foerste, but the following locality will serve as a reference section.

Reference section of Crab Orchard Group

[Measured along United States Highway 150 just east of Cedar Creek, 2.5 mi west of Crab Orchard, Crab Orchard Quadrangle, Lincoln County, Kentucky. Measured by J. L. Gualtieri, 1963; supplemented by G. C. Simmons, 1966; modified by R. C. McDowell, 1978]

	Thickness (feet)
Devonian:	
Boyle Dolomite:	
8. Red, clayey residum with slicified silicified horn and colonial which litter lower slopes; contact approximate, not measured.	
Silurian:	
Crab Orchard Group:	
Alger Shale:	
Estill Shale Member:	
7. Covered, greenish soil----------	24
6. Shale, grayish-yellow-green, weathers green, with sparse thin beds of very dusky red shale ----------------------	21
5. Covered, probably green shale with sparse dolomite lentils---	23
Waco Member(?):	
4. Shale, grayish-yellow-green to dusky-yellow-green, weathers green; contains a few thin, grayish-orange dolomite lentils, including a 4-in-thick, fine-grained dolomite bed at base --	4
Lulbegrud Shale Member (?):	

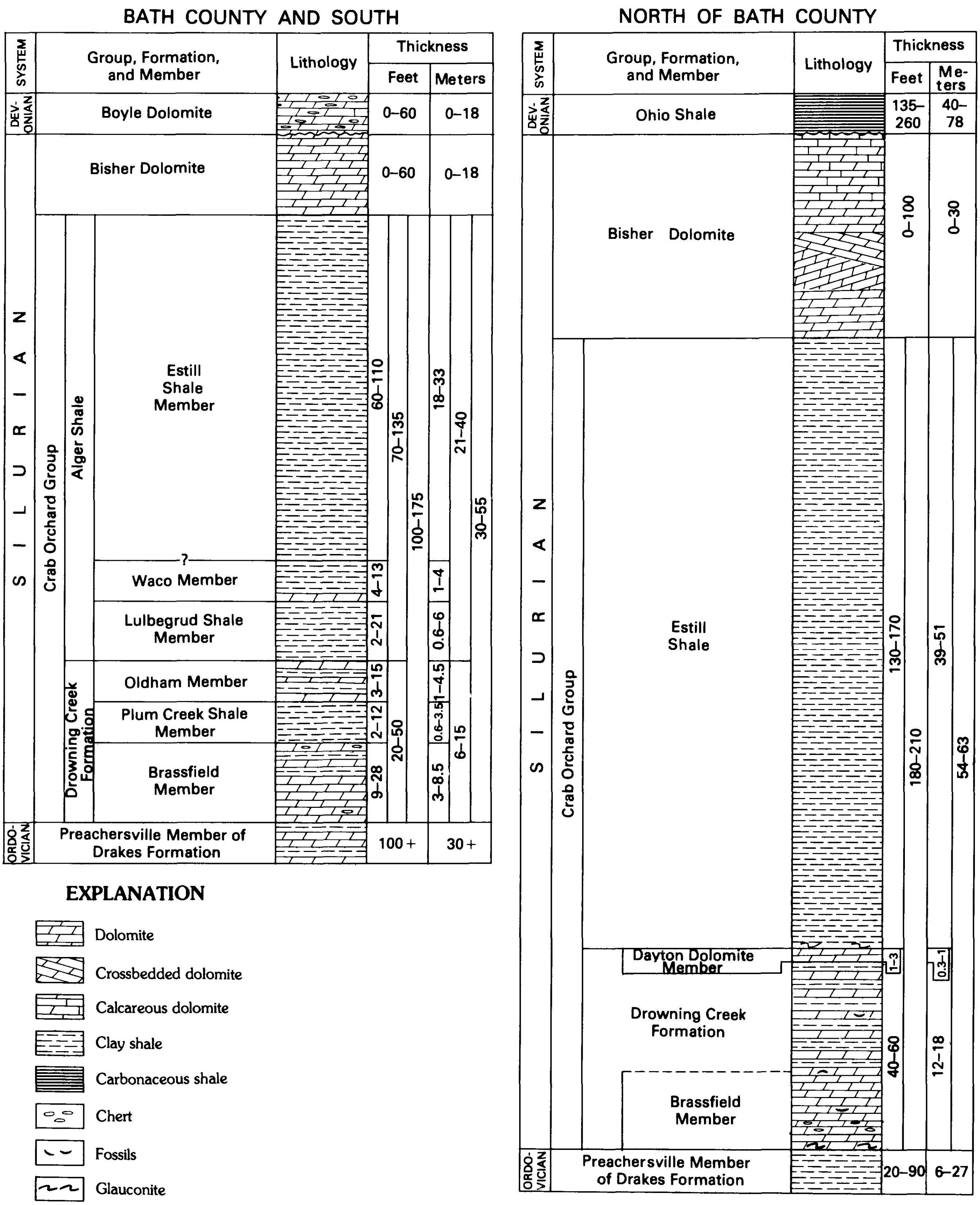

FIGURE 3.—Generalized columnar sections of Silurian rocks east of the Cincinnati Arch in Kentucky.

SYSTEM	Linney (1882)	Campbell (1898)	Foerste (1906)	Rexroad and others (1965)	U.S.G.S.–K.G.S. MAPPING PROGRAM (1964–1978): Nomenclature used	Map units used on most maps: Bath Co. and south	Map units used on most maps: North of Bath Co.	This report: Bath County and south	This report: North of Bath County
DEVONIAN	Corniferous limestone	Panola formation	Devonian limestone horizon	Boyle Limestone	Boyle Dolomite	Boyle Dolomite	Ohio Shale	Boyle Dolomite	Ohio Shale
SILURIAN	Crab Orchard shale		Crab Orchard Division: Alger formation: Estill clay	Crab Orchard Group: Estill Shale	Crab Orchard Formation: Estill Shale Member	Upper part of Crab Orchard Formation	Upper part of Crab Orchard Formation	Crab Orchard Group: Alger Shale: Estill Shale Member	Crab Orchard Group: Estill Shale
			Waco limestone	Noland Formation: Waco Member; Dayton Limestone Member	Waco Member		Lower part of Crab Orchard Formation and Brassfield Formation	Waco Member	Drowning Creek Formation: Dayton Dolomite Member
			Lulbegrud clay	Lulbegrud Shale Member; undifferentiated	Lulbegrud Shale Member			Lulbegrud Shale Member	undifferentiated
			Indian Fields formation: Oldham limestone	Oldham Limestone Member	Oldham Member	Lower part of Crab Orchard Formation and Brassfield Dolomite		Drowning Creek Formation: Oldham Member	
			Plum Creek clay	Plum Creek Clay Member	Plum Creek Member			Plum Creek Shale Member	?
	Medina sandstone		Brassfield limestone	Brassfield Formation; Belfast Member	Brassfield Dolomite/formation			Brassfield Member	Brassfield Member
ORDOVICIAN		Richmond formation	Richmond Division	Ordovician rocks	Drakes Formation			Preachersville Member of Drakes Formation	Preachersville Member of Drakes Formation

FIGURE 4.—Nomenclature of the pre-Bisher Silurian rocks east of the Cincinnati Arch in Kentucky.

3. Shale, grayish-green ---------- 2

Drowning Creek Formation:

Oldham, Plum Creek Shale, and Brassfield Members:

2. Dolomite, grayish-orange to greenish-gray, weathers reddish-brown; fine- to coarse-grained, coarser in upper part; thin-bedded, except basal bed 4 to 6 ft thick; shale interbeds as much as 3 in thick; fossils include horn corals, sparse shelly material at base; cogwheel-shaped crinoid columnals 15 ft above base --------------- 23

Total thickness of Crab Orchard Group --- 97

Ordovician:

Drakes Formation:

1. Shale, grayish-green, not measured.

The Crab Orchard Group is thickest, about 200 ft, at the northern end of its outcrop belt where it is overlain by the Bisher Dolomite; elsewhere, the group has been truncated by the unconformity at the base of the Devonian. Table 1 shows that the carbonate rocks of the Crab Orchard Group are predominantly dolomites in the south but become more calcite-rich northward and in Ohio are predominantly limestone. Mineralogy of some shales of the Crab Orchard Group is presented in table 2.

The sequence of rocks now included in the Crab Orchard Group, because of the lithologic difference between its upper and lower parts (fig. 3), has previously been subdivided into two or three formations by earlier workers (fig. 4). The USGS–KGS geologic mapping program has shown, however, that these formations are not appropriate and were not used as map units in most of the quadrangles. Consequently, the Crab Orchard Group is herein subdivided into three formations: the Drowning Creek Formation (new name) at the base and the Alger Shale (in the south) and Estill Shale (in the north) above it (figs. 3, 4).

DROWNING CREEK FORMATION (here named)

The top of the Brassfield limestone, as defined by Foerste (1906, p. 27–38) and used by many subsequent

TABLE 1.—*Calcium-magnesium analysis of samples from carbonate rocks of the Crab Orchard Group*

[Analysis by "single solution" method. Analyst: Leonard Shapiro, U.S. Geological Survey. Calculation of $CaCO_3$, $MgCO_3$, total carbonate, dolomite, and calcite by R. C. McDowell. Collecting localities: W, Winston, State Route 52, Estill County, KY; B, The Bend, Madison County, Ky.; T, Tollesboro, State Route 10, Lewis County, Ky.; LF, Lick Fork, State Route 41, Adams County, Ohio; FR, Flat Run, State Route 73, Adams County, Ohio (see fig. 2). Stratigraphic units: Sdc, Drowning Creek Formation; Sdcbe, "Belfast bed;" Sdcb, Brassfield Member; Sdco, Oldham Member; Sdcd, Dayton Dolomite Member; Saw, Waco Member of Alger Shale.]

Field number	Feet (m) above base of Silurian	Stratigraphic unit	CaO	MgO	$CaCo_3$	$MgCo_3$	Total carbonate	Dolomite	Calcite	Rock name; remarks
W–1 —	0 (0)	Sdcb	25.0	15.8	44.8	33.2	78.0	73.0	5.0	Dolomite.
W–2 —	4.5 (1.5)	---- do ----	23.5	14.4	42.1	30.2	72.3	66.5	5.8	Do.
W–3 —	16.5 (5)	---- do ----	28.8	13.6	51.6	28.6	80.2	62.8	17.4	Calcitic dolomite.
W–4 —	19.5 (6)	---- do ----	30.1	16.0	53.9	33.6	87.5	73.9	13.6	Dolomite.
W–5 —	27 (8)	Sdco	27.7	13.9	49.6	29.2	78.8	64.2	14.6	Calcitic dolomite.
W–6 —	34 (10)	---- do ----	26.1	15.0	46.7	31.5	78.2	69.3	8.9	Dolomite.
W–7 —	51.5 (15)	Saw	29.1	17.1	52.1	35.9	88.0	79.0	9.0	Do.
B–1 —	0 (0)	Sdcb	26.0	15.1	46.5	31.7	78.2	69.7	8.5	Do.
B–2 —	2 (0.6)	---- do ----	32.3	17.0	57.8	35.7	93.5	78.5	15.0	Do.
B–3 —	6 (2)	---- do ----	32.0	16.2	57.3	34.0	91.3	74.8	16.5	Calcitic dolomite.
B–5 —	14.5 (4)	---- do ----	30.2	17.6	54.1	37.0	91.1	81.3	9.8	Dolomite; "bead bed."
B–6 —	15.5 (4.5)	---- do ----	29.7	18.3	53.2	38.4	91.6	84.5	7.1	Do.
B–7 —	18 (5)	Sdco	27.1	14.9	48.5	31.3	79.8	68.8	11.0	Dolomite.
B–8 —	23 (7)	---- do ----	30.5	16.9	54.6	35.5	90.1	78.1	12.0	Do.
B–9 —	28 (8.5)	---- do ----	28.2	16.0	50.5	33.6	84.1	73.9	10.2	Do.
B–10 —	42 (13)	Saw	28.8	16.1	51.6	33.8	85.4	74.4	11.0	Do.
T–1 —	0 (0)	Sdcbe(?)	27.0	13.6	48.3	28.6	76.9	62.8	14.1	Calcitic dolomite.
T–2 —	5 (1.5)	Sdcb	21.0	1.2	37.6	23.5	61.1	51.7	9.4	Dolomite.
T–3 —	10 (3)	---- do ----	29.9	14.6	53.5	30.7	84.2	67.5	16.7	Calcitic dolomite.
T–5 —	62 (19)	Sdcd	28.2	16.4	50.5	34.4	84.9	75.8	9.1	Dolomite.
LF–1 —	3.5 (1)	Sdcbe	24.7	12.8	44.2	26.9	71.1	59.2	11.9	Dolomitic limestone.
LF–2 —	4.5 (1.5)	Sdc	32.2	10.8	57.6	22.7	80.3	49.9	30.4	Do.
LF–3 —	6.5 (2)	---- do ----	50.8	1.8	90.9	3.8	94.7	8.4	86.3	Limestone.
LF–4 —	11 (3)	---- do ----	22.6	3.2	40.5	6.7	47.2	14.7	32.5	Dolomitic limestone.
LF–5 —	15.5 (4.5)	---- do ----	30.4	16.5	54.4	34.7	89.1	76.3	12.8	Do.
LF–6 —	22 (7)	---- do ----	52.5	1.2	94.0	2.5	96.5	5.5	91.0	Limestone.
LF–7 —	40 (12)	---- do ----	53.2	2.2	95.2	4.6	99.8	10.2	89.6	Limestone; "bead bed."
LF–8 —	52 (16)	Sdcd	15.1	8.3	27.0	17.4	44.4	38.3	6.1	Dolomitic mudstone.
FR–1 —	0 (0)	Sdcbe	21.4	9.9	38.3	20.8	59.1	45.7	13.4	Calcitic dolomite.
FR–2 —	5 (1.5)	---- do ----	26.0	12.9	46.5	27.1	73.6	59.6	14.0	Do.

TABLE 2.—*Mineralogy of samples from shales of the Crab Orchard Group*

[X-ray analyses by Harry A. Tourtelot and Betty Ternes. Samples from the R. B. Ellington number 1 core hole, Rowan County, Ky., collected by John H. Peck.]

Sample number	Feet (m) above base of Silurian			Stratigraphic unit	Mineralogical composition: Clay minerals: Mixed	Illite	Chlorite	Kaolinite	Total clay	Other minerals: Quartz	K-spar	Calcite	Dolomite	Siderite	Pyrite	Total
164	213	(65)	Alger Shale	Estill Shale Member	8	70	—	22	45	18	—	—	32	—	5	100
190.5	186.5	(55)	Alger Shale	———do———	23	65	2	10	65	20	—	—	15	—	—	100
223.5	153.5	(45)	Alger Shale	———do———	5	84	—	11	60	21	tr	—	9	—	9	100
243.5	133.5	(40)	Alger Shale	———do———	5	81	4	10	60	19	—	—	8	5	10	102
269	108	(30)	Alger Shale	———do———	11	77	6	6	70	24	1	—	5	—	—	100
294	83	(25)	Alger Shale	———do———	5	84	4	7	55	25	—	6	5	—	—	100
301	76	(23)	Alger Shale	———do———	17	78	4	1	65	22	tr	—	6	—	7	100
302	75	(23)	Alger Shale	———do———	9	84	—	7	75	16	tr	—	9	—	—	100
307	70	(21)	Alger Shale	Lulbegrud Shale Member	4	80	6	10	55	28	—	7	—	—	10	100
319	58	(18)	Alger Shale	———do———	10	85	—	5	60	18	—	—	—	18	—	96
320	57	(17)	Drowning Creek Formation	Oldham Member	10	85	—	5	20	30	—	—	—	50	—	100
334.5	42.5	(13)	Drowning Creek Formation	Plum Creek Shale Member	—	92	2	6	77	17	—	—	—	6	—	100

workers, is located by a faunal horizon, distinctive cogwheel-shaped crinoid columnals (fig. 5) in a thin zone that has come to be called the "bead bed" (Foerste, 1935, p. 125; Rexroad and others, 1965, p. 10, see also p. 16 and 32; Rexroad, 1967, p. 16). The contact loses its lithologic character north of Bath County, Ky., and is determined, in this usage, by the "bead bed" alone. The use of a faunal horizon as a formational boundary is now generally regarded as undesirable, and it has led to difficulties in this case: inasmuch as the "bead bed" is repeated in many sections and rises rapidly through the section northward, the top of the Brassfield defined in this way is difficult, and locally impossible, to recognize in the north. Figure 6 illustrates nomenclatural differences arising from this lack of precise definition. Moreover, the "bead bed" has proved impractical for subsurface correlation (Horvath, 1967, p. 350). In part because of these problems, previous workers have redefined Foerste's Brassfield to include different amounts of the strata overlying his Brassfield. For example, Branson and Branson (1947) include the Plum Creek clay as a member of the Brassfield because the conodont faunas were found to be "identical," and O'Donnell (1967) included in the Brassfield the entire Noland Formation of Rexroad and others (1965). The long-established usage of the name in the original sense suggests that it should not be completely redefined but retained in a restricted sense. Therefore, because of its thinness in the south and lack of definition in the north, the Brassfield east of the Cincinnati Arch, which has proved unmappable in most places, is reduced in rank to a member of the Drowning Creek Formation.

Instead of the top of the Brassfield limestone of Foerste (1906), most quadrangle mappers have selected a higher horizon, within the Crab Orchard Formation as used by earlier workers, for the separation of the Crab Orchard Group into two mappable lithostratigraphic

FIGURE 5.—Distinctive cogwheel-shaped crinoid columnals and other large crinoid columnals, near the top of the Brassfield Member of the Drowning Creek Formation at Colfax, Fleming County, Ky. This is the "bead bed" of Rexroad and others (1965).

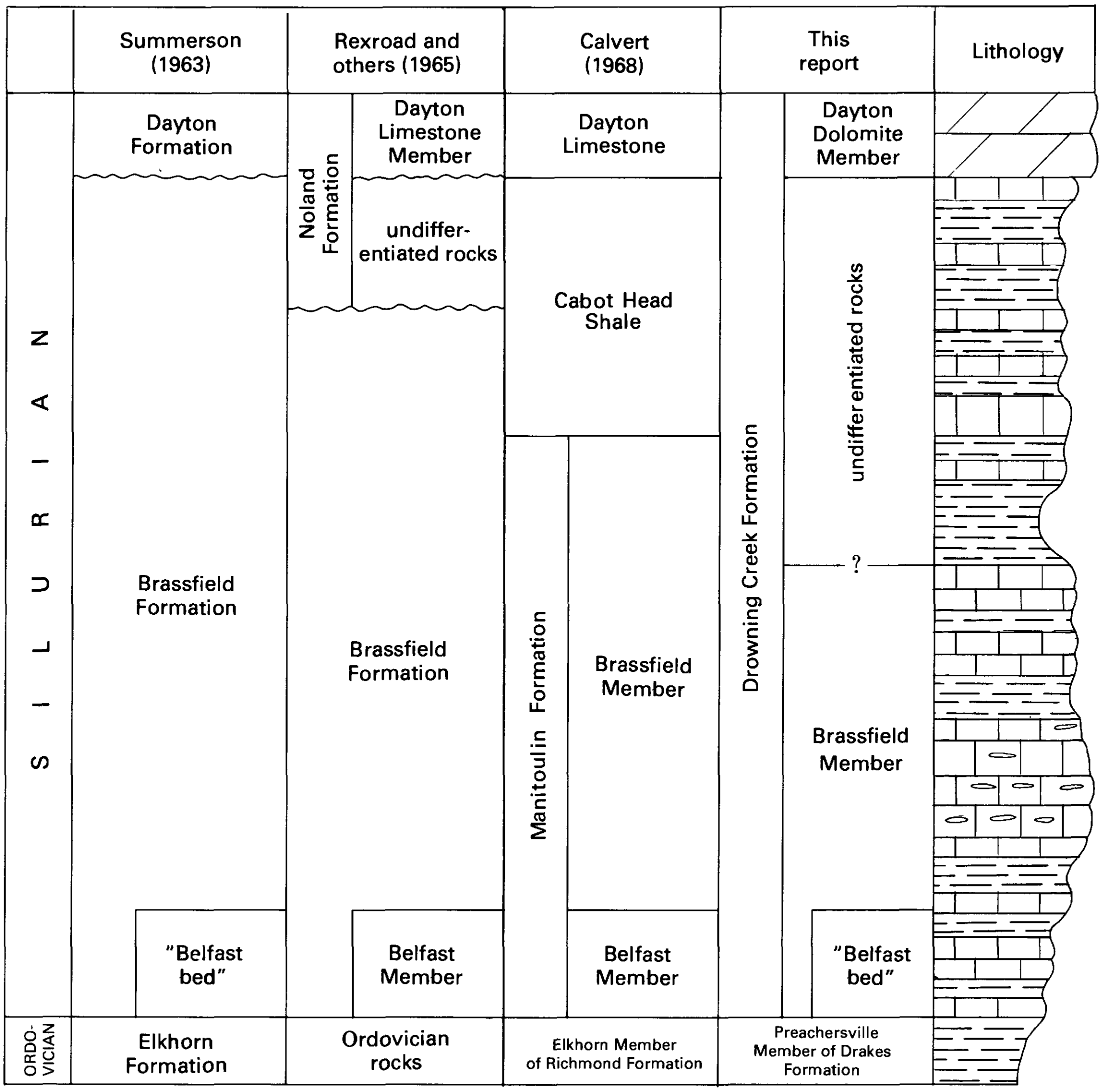

FIGURE 6.—Comparison of nomenclature applied by different authors to an exposure at Ohio Brush Creek, Adams County, Ohio. The "bead bed" is at the top of the Brassfield Formation of Rexroad and others (1965). See figure 3 for explanation of lithology. Total thickness of Silurian is about 60 ft.

units. In Bath County and southward, this horizon has predominantly been the top of the Oldham limestone of Foerste (1906, p. 47–50). A twofold subdivision of the Crab Orchard at this horizon was anticipated originally by Campbell (1898, p. 2) and even suggested by Foerste himself (1906, p. 62) on lithologic grounds, calling it "more natural" from a lithological standpoint; he declined to do so only on the mistaken belief that his Oldham of Kentucky correlated with the Dayton limestone of Orton (1871) in Ohio, which had previously been placed in the upper division there.

To separate the Crab Orchard Group into two mappable units of some lithologic homogeneity south of Fleming and Rowan Counties, the name Drowning Creek Formation is here applied to a sequence of predominantly dolomite beds from the base of the Brassfield Member to the top of the Oldham Member. The intervening Plum Creek Shale Member completes the subdivision of this formation. The name is taken from Drowning Creek, a tributary of the Kentucky River, which forms the boundary between Madison and Estill Counties in the Panola Quadrangle. An excellent exposure along State Highway 52 in Estill County, just east of Drowning Creek, is designated as the type section.

Type section of the Drowning Creek Formation

[Measured in cuts along Kentucky Route 52 just east of Drowning Creek, near Winston, Panola Quadrangle, Estille County, Kentucky. Measured by R. C. McDowell, 1975]

	Thickness (feet)
Devonian:	
Boyle Dolomite:	
8. Dolomite, light-gray, fine- to coarse-grained, thin-bedded to laminated; chert nodules, mostly dark-gray with lighter gray rims, abundant from a few ft above base to near top; overlain by black shale interbedded with dolomite in beds 0.5 to 1 ft thick at top of cut; not measured, thickness estimated	25
Silurian:	
Crab Orchard Group:	
Alger Shale (in part):	
Waco Member:	
7. Dolomite, light-gray, fine-grained, in two beds, upper bed 0.5 ft thick, lower bed 2.5 ft thick; base of beds with molds of "burrows"	3
Lulbegrud Shale Member:	
6. Shale, clayey, greenish-gray, dolomite	11
Total thickness of Alger Shale	14
Drowning Creek Formation:	
Oldham Member:	
5. Dolomite, gray, fine- to coarse-grained, in beds less than 1 in to as much as 6 in thick, thicker near base; some beds fossiliferous; about 80 percent of unit; interbedded with greenish-gray shale in partings and sets 1 to 4 in thick, most abundant in upper 6 ft	12
Plum Creek Shale Member:	
4. Shale, clayey, greenish-gray, about 80 percent of unit, with interbeds of dolomite, mostly less than 1 in thick, but one bed 2 ft below top 8 in thick	7.5
Brassfield Member:	
3. Dolomite, medium- to dark-gray and brownish-gray, medium-grained, in irregular beds 1 to 15 in thick, thickest near top; vuggy, petroliferous; about 85 percent of unit; interbedded with minor grayish-green shale in partings and sets as much as 4 in thick; distinctive cog-wheel-shaped crinoid columnals as much as 0.75 in across 2 ft below top	14
2. Dolomite, dark-gray, fine-grained, in a single massive bed; base appears comformable	5.5
Total thickness of Drowning Creek Formation	39
Ordovician:	
Drakes Formation:	
1. Shale, greenish-gray, dolomitic; several feet well exposed, not measured.	

A similar exposure occurs along the highway to the west of Drowning Creek. At both of these localities, pre-Boyle erosion has removed all of the Estill Shale Member and the upper part of the Waco Member of the Alger Shale.

Northward from Bath County, Ky., the Lulbegrud Shale Member of the Alger Shale thins (see pl. 1) and the top of the Oldham Member cannot be readily determined. The top of the Drowning Creek Formation is, therefore, raised to the horizon that was used in the USGS–KGS mapping program in that area, the top of its Dayton Dolomite Member, or a maximum rise of about 7.5 ft. A reference section for this expanded Drowning Creek Formation can be seen in road cuts near Tollesboro in Lewis County, Ky.

Reference section of Drowning Creek Formation

[Measured from cuts along Kentucky Route 10, lower part southwest of Cabin Creek and upper part northeast of creek, Tollesboro Quadrangle, Lewis County, Ky. Measured by F. A. Schilling, Jr. and J. H. Peck, 1963; modified by R. C. McDowell, 1978]

Silurian:	
Crab Orchard Group:	
Estill Shale (in part):	
9. Shale, greenish-gray, with zones of reddish-brown; disseminated green glauconite grains near base. Only lowermost 7.5 ft exposed	7.5
Total thickness of Estill Shale exposed	7.5
Drowning Creek Formation:	
Dayton Dolomite Member:	
8. Dolomite, light-gray, fine-grained,	

Thickness (feet)

in beds as much as 1 ft thick in upper part, thinner beds in lower -------------------- 3

Lulbegrud Shale (?) and Oldham (?) Members, undivided:

7. Shale, clayey, greenish-gray, in sets from a few inches to 4 ft thick, interbedded with dolomite, light-gray, fine-grained, calcareous, in thin, irregular beds, commonly with fossils: horn corals, crinoids, bryozoa; ferruginous dolomite bed at base --------------------11

Plum Creek Shale(?) Member:

6. Shale, clayey, greenish-gray, with a single very irregular 8-in-thick bed of medium-grained ferruginous dolomite containing profuse cogwheel-shaped crinoids about 4 ft below top, and sparse, thin, even-bedded, light-gray, fine-grained dolomite beds interbedded in and making up about a quarter of lower half of unit -16

Brassfield(?) Member:

5. Dolomite, greenish- and brownish-gray, fine- to medium-grained, in beds less than 1 ft thick, interbedded with greenish-gray shale; crossbedded hematitic limestone bed near middle of unit --------------10
4. Dolomite, brownish-gray, medium-grained, massive, with white chert nodules --------- 5
3. Dolomite, gray, fine- to medium-grained, in thin irregular beds with clay partings ---------- 7
2. Dolomite, gray to greenish-gray, medium- to coarse-grained, in a single bed with common calcite nodules; glauconitic --------- 2

Total thickness of Drowning Creek Formation ---54

Ordovician:

Preachersville Member of Drakes Formation:

1. Shale, greenish-gray with reddish-brown zones and with thin dolomitic limestone and interbeds, upper part----------10

Establishment of the Drowning Creek Formation brings the stratigraphic nomenclature into accord with widespread field mapping practices. In most quadrangles, it is equivalent to the map unit labelled "Brassfield Formation and lower part of Crab Orchard Formation"; for example, Colfax Quadrangle (McDowell, 1976). Other formations erected by previous workers, such as the Indian Fields formation of Foerste (1906, p. 60–61) and the Noland formation of Rexroad and others (1965, p. 14–16) (fig. 4), have not been found useful in mapping and were not used in the quadrangle mapping program. Indeed, Foerste (1906, p. 61) himself suggested the Indian Fields not be used for mapping.

The Drowning Creek Formation ranges in thickness from 20 to 50 ft south of Bath County and from 40 to 60 ft in the north.

BRASSFIELD MEMBER

The Brassfield Member of the Drowning Creek Formation, reduced in rank herein, is the basal stratigraphic unit of the Silurian in Kentucky; west of the Cincinnati Arch, it retains the rank of formation (Peterson, 1981).

The Brassfield Member is defined as a sequence of dolomite (or limestone) beds, with minor interbedded shale and locally with chert nodules and lenses, from the top of the Ordovician to the base of the Plum Creek Shale Member of the Drowning Creek. South of Bath County, Ky., this coincides with the Brassfield limestone as defined by Foerste (1906, p. 27–30). North of Bath County, the members of the Drowning Creek Formation became progressively less distinct. The top of the Brassfield is arbitrarily taken to be the top of the predominantly dolomite or limestone section that occurs at the base of the Silurian, below a shale-rich interval (see reference section of Drowning Creek Formation above). As described above, previous workers have placed the top of the Brassfield Member at the top of a bed containing distinctive cogwheel-shaped crinoids, the "bead bed"; for example, Rexroad and others (1965, p. 10). The "bead bed" occurs near the top of the Brassfield south of Bath County but rises above it into the overlying shale sequence to the north; it is about 3 ft higher at the reference section above, in Lewis County, Ky., and about 16 ft higher at Ohio Brush Creek in Adams County, Ohio (see pl. 1 and fig. 6).

Foerste (1906, p. 27) designated exposures along the Louisville and Atlantic railroad, between Brassfield and Panola in Madison County, Ky., as typical of the formation. The railroad has since been abandoned, and these outcrops are neither as accessible nor as well exposed as they were then, so the nearby exposure along State Highway 52 in Estill County, the type section of the Drowning Creek Formation, can serve as a reference section for the Brassfield Member.

The Brassfield Member occurs throughout the area of distribution of Silurian rocks east of the Cincinnati Arch (fig. 1). Where the complete unit is present in outcrop, it ranges in thickness from about 9 to 28 ft and averages about 20 ft. In Kentucky, it is composed predominantly of dolomite with partings and thin interbeds of clay shale which are more abundant in the upper part of the member. Near the Ohio River, some of the dolomite beds are calcareous; northward, in Ohio, limestones predominate over dolomite in the carbonate portion of the unit (table 1), and shale interbeds are thicker and more abundant.

In the southern half of the main outcrop belt, the basal part of the Brassfield is composed of fine- to medium-grained, gray, silty, generally unfossiliferous dolomite in beds as much as 6 ft thick that constitute a ledge-forming unit as much as 10 ft thick. Northward to the Ohio River, the basal Brassfield ledges are argillaceous and glauconitic and are thinner bedded, with partings and thin interbeds of shale. The lowermost few inches of the member contain sparse to abundant coarse rounded quartz sand grains in Montgomery and Clark Counties and a thin basal conglomerate locally near Berea (Weir, 1976). The basal beds are overlain in the northern part of the outcrop belt by a sequence of medium- to thick-bedded dolomite containing white to light-gray chert in irregular lenses and nodules generally 1 to 6 in thick (figs. 7, 8). This sequence is about 5 ft thick at the Ohio River and thins gradually southward to a pinchout near Camargo in Montgomery County. The remainder of the Brassfield Member, ranging in thickness from 5 to 20 ft, consists of interbedded dolomite and shale (fig. 9.). The dolomite is generally gray, fine- to medium-grained, and moderately fossiliferous in beds as much as 1.5 ft but generally 4 to 6 in thick and makes up about 80 percent of the unit. South of Fleming County, a distinct lithologic break occurs between the dolomite-bearing Brassfield and the Plum Creek Shale Member. Northward, the Plum Creek has an increasing amount of dolomite occurring as interbeds, and its contact with the Brassfield Member becomes increasingly arbitrary. Moreover, the uppermost dolomite beds of the Brassfield in Bath County and southward are marked by distinctive fossils and mineral deposits including the cogwheel-shaped crinoid columnals ("bead bed"), described above (fig. 5), the brachiopod *Cryptothyrella quadrangularis,* and by an oolitic hematite-chamosite-bearing sequence, especially in Bath County, as much as 3 ft thick that has been exploited near Owingsville as the Rose Run iron ore (McDowell, 1976). These beds, which extend as a conspicuous but thin marker unit from Powell County northward to Fleming County and less clearly beyond, are commonly characterized by crossbedding and large-scale ripple marks (pararipples).

The Brassfield Member has been subdivided by previous workers into both formal and informal subunits. Foerste (1896, p. 163–164) established the "Belfast bed," a sequence of massive-weathering argillaceous limestones 3 to 6 ft thick at the base of the Brassfield in Highland County, Ohio. Foerste originally considered this bed latest Richmondian in age but later recognized it as a basal and transitional part of the Brassfield that he reported as extending southward to Hillsboro (Fleming County), Ky. (Foerste, 1931, p. 183; 1935, p. 188). Rexroad and others (1965) applied the name at two localities farther south, including the type section of the Brassfield, although not elsewhere in the same area, a usage that appears to be inconsistent with the original definition. Because of the thinness of the unit and disagreement over its identification and distribution (O'Donnell, 1967, p. 33–34), the term "Belfast" has not been found useful in Kentucky.

Rexroad and others (1965, p. 9–11) recognized two other informal lithologic subunits within the Brassfield south of Bath County, Ky., and four others in Ohio. O'Donnell (196, p. 31) found as many as five informal members in southern Ohio and northern Kentucky. John H. Peck (written commun., 1970) described six distinct lithofacies in Kentucky, only one of which (interbedded dolomite and shale, generally the uppermost part of the member) was distributed throughout the outcrop area. No subdivision of the Brassfield was made during the USGS–KGS mapping project, and none is proposed herein, although the member can be considered in a general way to contain a thicker bedded lower part and a thinner bedded upper part that includes interbedded shale.

PLUM CREEK SHALE MEMBER

The Plum Creek clay was named by Foerste (1906, p. 44–47) for about 5.5 ft of clay shale above the Brassfield "wave-marked limestone" and below the interbedded dolomite and shale of his Oldham limestone along Plum Creek, near Clay City (Powell County), Ky. Foerste considered it the basal unit of his Crab Orchard but noted that it is difficult to distinguish from the overlying "Oldham limestone" north of Owingsville (Bath County), Ky. (Foerste, 1935, p. 130). Simmons (1967a) adopted the Plum Creek Member of the Crab Orchard Formation for use by the U.S. Geological Survey in the USGS–KGS mapping project. Because shale is the dominant and characteristic lithology, the name is here amended to Plum Creek Shale Member and reassigned to the Drowning Creek Formation.

The Plum Creek is composed of greenish-gray, poorly fissile clay shale that is plastc when wet, with a few beds and lenses of dolomite that become more numerous

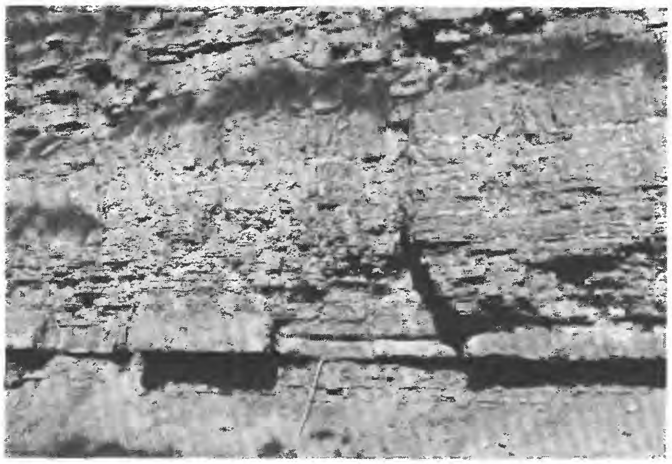

FIGURE 7.—Roadcut exposure of the Brassfield Member of the Drowning Creek Formation showing lower part with cherty dolomite overlain by interbedded dolomite and shale. Lithology and bedding shown are typical of the Brassfield in the northern part of the outcrop belt. Base of Silurian at top of 5 ft rod. Kentucky Route 10, 2.5 mi east of Tollesboro, Ky.

FIGURE 8.—Irregular-bedded and nodular chert in vuggy, medium-grained dolomite of the lower part of the Brassfield Member of the Drowning Creek Formation. Chert is white to light gray and apparently has replaced fossiliferous limestone. Roadcut on Kentucky Route 10 about 2.5 mi east of Tollesboro, Ky.

FIGURE 9.—Roadcut exposure of the Brassfield Member of the Drowning Creek Formation near Palmer, Estill County, Ky., showing characteristic bedding style. Base of Silurian is at hammer. Rod is 5 ft long. East side of Kentucky Route 89, 0.4 mi north of Palmer, Ky.

to the north, with the result that recognition of the Plum Creek is uncertain north of the Colfax section (pl. 1). The unit ranges in thickness from 2 to 12 ft south of Colfax.

OLDHAM MEMBER

The Oldham limestone was named by Foerste (1906, p. 47–50) for about 14 ft of "thin limestone interbedded with clay" overlying his Plum Creek clay along the railroad east of Brassfield near Oldham Branch, essentially the original type section of Brassfield. Foerste (1906, p. 50) noted the difficulty in distinguishing the Oldham from the Plum Creek north of Bath County and seemed to regard both of these units valid only south of Owingsville. Simmons (1967a) adopted the Oldham Member of the Crab Orchard Formation for the mapping project. The Oldham Member is herein reassigned as a member of the Drowning Creek Formation and is clearly identifiable as far north as Colfax and tentatively northward to Ohio (pl. 1).

The Oldham is composed of interbedded dolomite and shale. The dolomite, about 60 to 80 percent of the unit, is gray, fine- to coarse-grained, commonly fossiliferous, and locally calcitic. Fossils are mostly brachiopods with bryozoans, crinoid columnals, and rare horn corals and worm(?) trails; all fossils are generally poorly preserved. The shale is greenish-gray, plastic when wet, and poorly fissile. The dolomite occurs in even to irregular beds from 1 in to 1 ft, most commonly about 2 in thick. The interbedded shale is in beds as much as 1 ft thick but most commonly occurs as partings or beds 1 to 2 in thick. From the base upward, the dolomite beds tend to be thinner, and shale becomes more abundant. The Oldham Member ranges in thickness from about 3 to 15 ft but is about 7 to 12 ft thick in most places.

The Oldham Member is present throughout most of the Silurian outcrop belt but is not present in the isolated outcrop areas to the south and west in Boyle and Pulsaski Counties, where the equivalent beds were removed by erosion prior to deposition of Devonian sedimentary rocks (fig. 2).

DAYTON DOLOMITE MEMBER

Orton (1871, p. 149) applied the term Dayton stone, previously used as a commercial name, to the lower 5 to 10 ft of "Niagara rocks" in the area of Dayton, Ohio. Foerste (1935, p. 150) noted that the Dayton limestone could be traced southward into Lewis County, Ky. Although the name was not used in the mapping project, the Dayton was mapped as top of the lowermost Silurian map unit, "Brassfield Formation and lower part of the Crab Orchard Formation (combined)," essentially throughout its area of occurrence in Fleming and Lewis Counties; this map unit corresponds to the Drowning Creek Formation as defined herein. In southern Fleming County, where its Oldham Member is clearly identifiable, the upper contact of the Drowning Creek is arbitrarily dropped about 7 ft to the top of the Oldham, and the Dayton lies within and is a member of the Alger Shale (see pl. 1). The unit is herein termed the Dayton Dolomite Member of the Drowning Creek Formation (or Alger Shale); in the literature it is commonly referred to simply as the "Dayton bed."

The Dayton is a light- to medium-gray, fine- to medium-grained calcareous dolomite that occurs in three or four beds totaling 1 to 3 ft in thickness (fig. 10). The dolomite is mostly dense and hard but locally porous or vuggy, and is generally devoid of fossils, except for trace fossils on bedding planes as in the basal part of the Waco (described below). The Dayton pinches out in southern Fleming and northern Bath Counties, and the stratigraphically equivalent basal Waco dolomite appears 2 or 3 miles to the south (McDowell, 1976). The gap in the outcrop between these beds has been shown by drilling to extend several miles eastward into the subsurface (pl. 1, section B–B'), and original continuity cannot be demonstrated, although it is suggested by their proximity, close lithological similarity, and stratigraphic position.

FIGURE 10.—Characteristic appearance of the Dayton Dolomite Member of the Drowning Creek Formation. North side of Kentucky Route 8 about 0.6 mi southeast of Concord, Lewis County, Ky.

ALGER SHALE

The upper of the two formations composing the Crab Orchard Group south of Colfax (Bath County) is herein designated the Alger Shale. The Alger, predominantly a shale unit, is made up of the Lulbegrud Shale, Waco, and Estille Shale Members. North of Colfax, the basal contact is arbitrarily raised to the top of the Dayton Dolomite of the Drowning Creek Member, equivalent to the Waco; the Alger, therefore, consists of the Estill Shale Member alone and is herein replaced in name by the Estill Shale.

The Alger was named by Foerste (1906, p. 61–62) for exposures along the railroad between Panola and Irvine in Estill County, and it is used here in precisely the same way south of Colfax. Foerste indicated exposures just north of Irvine, at White Oak Creek, as the "most instructive" section (see pl. 1, C-C').

The reference section for the Crab Orchard Group (p. 4–7) can serve also as a reference for the Alger. In the northern end of the Silurian outcrop belt and in a few isolated occurrences elsewhere, the Alger (Estill) is overlain conformably by the Bisher Dolomite and attains its greatest thicknesses; elsewhere, it is truncated by the regional pre-Devonian unconformity. The maximum thickness of the Estill Shale is about 170 ft near the Ohio River in Lewis County. It is not present in the isolated outcrops beyond the main Silurian outcrop belt.

LULBEGRUD SHALE MEMBER

Foerste (1906, p. 50–52) named the Lulbegrud Clay for exposures along and near Lulbegrud Creek in Clark and Powell Counties, where it was reported to be about 13 ft thick. The unit was adopted by Simmons (1967b) for use in the mapping project as the Lulbegrud Shale Member of the Crab Orchard Formation and is reassigned herein as the basal member of the Alger Shale, as in Foerste's original usage, south of the Colfax section. Northward, the unit cannot be recognized with assurance and may pinch out (see pl. 1).

The Lulbegrud is composed almost entirely of greenish-gray, poorly fissile shale, with sparse beds and lenses of dolomite generally an inch or less thick, and sparse megafossils, mostly brachiopods. Thin zones of reddish-brown shale are found in the unit in Bath County and locally elsewhere. The member overlies the Oldham Member of the Drowning Creek Formation and is overlain by the Waco Member of the Alger Shale. Where the basal dolomite bed of the Waco is absent, in Bath County, the boundary between the Lulbegrud and Estill Shale Members cannot be reliably identified (see Colfax section, pl. 1). Northward, the Dayton Dolomite Member of the Drowning Creek (or the Alger) overlies the Lulbegrud, but there the lower boundary of the Lulbegrud becomes less distinct as the unit becomes thinner. South of Colfax the Lulbegrud ranges from 2 to 21 ft in thickness.

WACO MEMBER

The Alger Shale is interrupted by a relatively thin interval of dolomite interbeds in its lower part. Foerste (1906, p. 52–59) applied the name Waco limestone "horizon" to this interval, noting that "although the clay predominates [in the Waco] . . . the presence of limestone is its characteristic feature." Simmons (1967b) renamed it the Waco Member of the Crab Orchard Formation, and it is returned herein to the Alger Shale as its Waco Member.

The Waco is characterized by a prominent basal ledge generally composed of two to three beds of dolomite totalling 0.5 to 3 ft in thickness (fig. 11), overlain by an interval as much as 10 ft thick consisting of several thin dolomite beds and lenses, commonly 1 to 2 in thick, containing abundant megafossils (horn corals, brachiopods, and bryozoans), and interbedded with greenish-gray shale beds a foot or more thick. The undersides of the basal dolomite beds commonly have trace fossils in the form of a network of interwoven finger-sized ridges (fig. 12). The thin fossiliferous dolomites, which serve to distinguish the upper part of the Waco from the overlying Estill Shale Member, are present in the southern part of the outcrop belt and disappear northward near Owingsville (Bath County); the basal dolomite beds extend a few miles further, to near Colfax (pl. 1). These basal beds appear to be equivalent in age and stratigraphic position to the Dayton Dolomite Member of the Drowning Creek Formation (or Alger Shale) which appears just north of Colfax and extends northward into Ohio.

FIGURE 11.—Basal dolomite beds of the Waco Member of the Alger Shale, overlying its Lulbegrud Shale Member. Near Polksville, Bath County, Ky.

FIGURE 12.—Trace fossils on underside of a dolomite bed at the base of the Waco Member of the Alger Shale, Kentucky Route 52, near Winston, Estill County; type section of the Drowning Creek Formation.

ESTILL SHALE MEMBER

The Estill clay was named by Foerste (1906, p. 59–60) for 56 ft of "white" clay shale overlying the Waco limestone "horizon" and forming the upper part of the Alger. The Estill Shale Member of the Crab Orchard Formation was adopted by Simmons (1967b) for the mapping program. In this report, the Estill in its type area is reassigned as the uppermost member of the Alger shale, but, in the northern part of the outcrop belt where the underlying Dayton Dolomite Member is included in the Drowning Creek Formation, the Estill is raised to the rank of formation, as it was used by Rexroad and others (1965). In the latter area, the Estill corresponds to the map unit "upper part of Crab Orchard Formation" as used in the mapping program [for example, Colfax Quadrangle (McDowell, 1976)].

The Estill is composed mainly of greenish-gray clay shale, with sparse reddish-brown zones about a foot thick especially near the base and particularly in the area where the Waco and the Dayton are missing. A few brownish-gray dolomite beds and lenses, generally less than 1 in thick, are commonly present, widely dispersed in the shale near the base of the unit, and less commonly higher. In Lewis County and adjacent Ohio, these sparse dolomite beds in the uppermost 30 ft of the Estill contain megafossils, mainly brachiopods, trilobites, and ostracodes, prompting Foerste (1931, p. 188–189) to split out a separate formation, the Ribolt clay, from the upper part of the Estill. Foerste's Ribolt was not used in the mapping program.

The Estill is overlain conformably by the Bisher Dolomite in most of the northern part of the area and in a few localities near Irvine (Estill County); elsewhere, it is truncated by a regional unconformity and is overlain paraconformably by rocks of Middle or Late Devonian age (fig. 13). Where the entire unit is present, it ranges in thickness from 60 to 170 ft.

PETROLOGY OF SHALES IN THE ALGER SHALE

Samples from the Alger Shale in the Farmers Quadrangle, Rowan County, Ky., were collected from the R. B. Ellington No. 1 core hole (see fig. 2 for location) by John H. Peck. A petrologic study of these samples by Harry A. Tourtelot (written commun., 1968), using X-ray methods and thin sections, is summarized below.

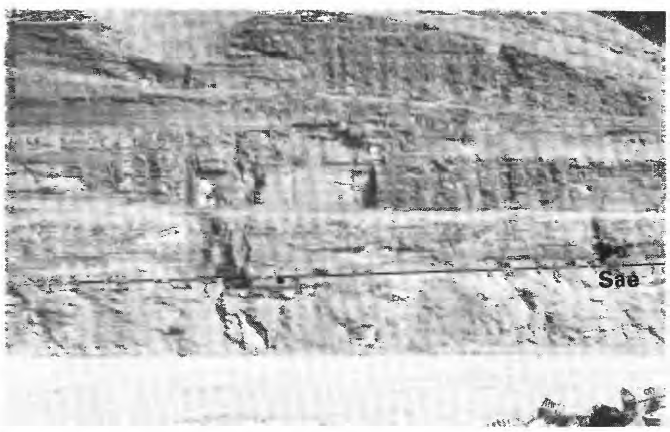

FIGURE 13.—Paraconformity between the Estill Shale Member of the Alger Shale (Sae) (Middle Silurian) and the Ohio Shale (Do; Upper Devonian). The contact is placed at a 0.5-in bed of fine-grained pyrite containing well-rounded fine to coarse grains of clear quartz and chert between beds of similar-appearing greenish-gray shales of the Estill and the Ohio and about 1 ft below the lowest bed of black carbonaceous shale. Roadcut on east side of Interstate Route 64 about 9 mi west of Morehead, Ky.; type section of the Three Lick Bed of the Ohio Shale (Provo and others, 1978).

Mineralogy of the shale samples is shown in table 2. The samples consist of clay, quartz, and dolomite with clay amounting to 45 percent or more, quartz ranging from 15 to about 35 percent, and dolomite ranging from 5 to 35 percent. Pyrite amounts to more than 10 percent in some samples and is present in all samples, even though in most the amount is too small to be detected by X-ray analysis. Glauconite is conspicuous only in samples from the lowermost foot of the Estill Shale Member of the Alger but is also present in small amounts in the lower part of the Estill and at the base of the Lulbegrud Shale Member of the Alger and in isolated grains in the other samples.

The clay fraction of all samples consists predominantly of illite with 10 to 15 percent expandable layers. Kaolinite and chlorite make up the rest of the clay fractions, with kaolinite the more abundant in most samples. The reddish-brown color of some of the shale is the result of unidentified very fine-grained oxidized iron compounds.

The recognizable quartz grains are mostly in the size range of 20 to 40 μm, although there are a few grains as large as 70 μm in the clays and many grains as large as 150 μm in glauconite-rich beds. There probably is much quartz finer than 20 μm. The small quartz grains are angular and commonly tabular in shape, with corroded edges.

Dolomite is more abundant in the upper part of the Estill than in the lower. It is interpreted to have formed during diagenesis in all samples. Most of the dolomite occurs in vaguely defined grains about 40 μm in maximum dimension, and smaller but sharply defined rhombs as much as 70 μm across are prominent in most of the thin sections.

Most of the glauconite occurs as dark-green spheroidal pellets 500 μm or so in size; but some are large, as much as 1 mm across, nearly black, and tabular or discoidal. The internal structure is uniformly random microcrystalline, and the mineral is of the disordered type with 10 to 15 percent expandable layers. The minerology and pattern of distribution suggest that the glauconite is detrital.

Bisher Dolomite

The Bisher member of the West Union formation was named, apparently on the basis of its fauna, by Foerste (1917, p. 190) for exposures near Hillsboro, Highland County, Ohio. Although he failed at that time to mention the thickness or lithology, he later reported it to be about 51 ft of "arenaceous limestones" (Foerste, 1935, p. 140). The name appears on most of the Kentucky geologic quadrangle maps as Bisher Limestone or Bisher(?) Limestone.

The Bisher is a light- to medium-gray, fine- to coarse-grained, partly calcareous, porous dolomite in thick beds (below) to thin beds (above) that weathers readily to a distinctive brownish-yellow friable rock in outcrop. The dolomite is locally silty or sandy and in part cross-bedded. It is commonly fossiliferous, in part fossil fragmental, with locally abundant brachiopods, trilobites, gastropods, bryozoans, less common crinoid columnals, and scattered algal heads. A bouldery breccia, composed of large rounded masses of dolomite jumbled within a dolomitic shale or argillaceous dolomite matrix, occurs irregularly at the top of the unit or less commonly within it (fig. 14). This breccia has been interpreted by Peck (1968, p. 52) as a solution-collapse deposit that predates the Upper Devonian Ohio Shale, which overlies the Bisher.

The formation is everywhere truncated by a regional pre-Devonian unconformity, which causes the irregular distribution of the Bisher in outcrop. The unit reaches a maximum of about 100 ft in thickness along the Ohio River and thins to a pinchout about 10 mi to the south. It reappears as thin erosional remnants (fig. 15) as much as 14 ft thick for another 30 mi southward to near Colfax (Bath County) and again further south near Irvine (Estill County), where it reaches a maximum of 60 ft in thickness. It is shown on nine geologic maps in the northern area of its occurrence and four in the Irvine area.

J. H. Peck (written commun., 1968) has suggested that the upper half, or about 50 ft, of the dolomite unit along the Ohio River may be correlative with the so-called Lilley formation, which overlies the Bisher in the Highland County area of Ohio. It is composed of dolomite that is generally coarser grained and more fossiliferous than that of the lower half of the unit.

FIGURE 14.—Lower part of the Bisher Dolomite exposed on the north side of Kentucky Route 10 about 6 mi northeast of Tollesboro, Ky. Line encloses a bouldery breccia unit composed of jumbled blocks and fragments of dolomite in a silty dolomitic shale matrix. The bouldery breccia is probably an accumulation of rubble and water-laid mud filling a pre-Upper Devonian solution channel in the Bisher.

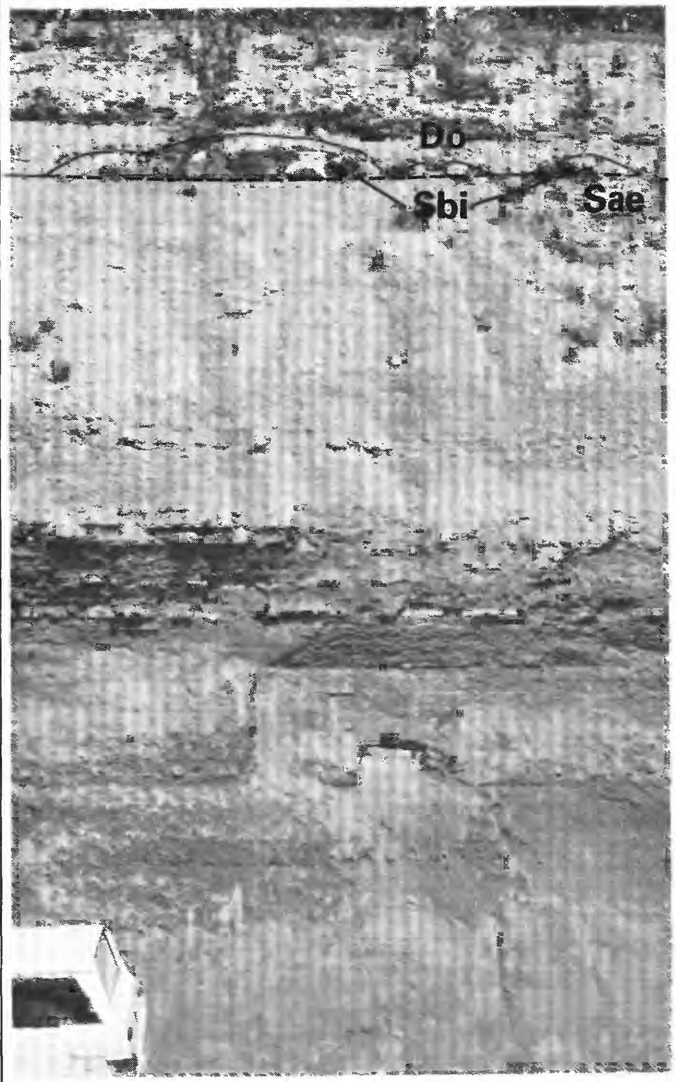

FIGURE 15.—Upper part of the Estill Shale Member of the Alger Shale (Sae) capped by erosional remnants of the Bisher Dolomite (Sbi) and by the Ohio Shale (Do; Upper Devonian). Thin tabular beds of dolomitic siltstone are interbedded with the clay shale in the Estill. Unconformity beneath the Ohio Shale has at least 3 ft of relief at this exposure. Roadcut about 10 mi west of Morehead, Rowan County, Ky.

Summary and Discussion of Nomenclatural Changes

The pre-Bisher Silurian on the east flank of the Cincinnati Arch, mapped as the Brassfield and Crab Orchard Formations with the mapping contact generally within the Crab Orchard, has been subdivided into three formations that conform more closely to the map units. These are, in ascending order, the Drowning Creek Formation (new name), the Alger Shale, and the Estill Shale (fig. 3).

The Brassfield is retained as a member of the Drowning Creek. The name Crab Orchard Formation is raised to group rank and redefined, principally because the lower boundary, as the unit was redefined by Foerste (1906, p. 62–63), is not mappable in part of the outcrop belt and the formation has not proven widely useful as a map unit in the remainder. The contact found most useful for mapping in this area is at the boundary between the two formations into which the Crab Orchard was divided by Foerste (1906); that is, at the base of his Alger, which is here revived. The lower unit of his Crab Orchard, his Indian Fields formation, was composed of his Plum Creek clay and Oldham limestone, which are here placed with the Brassfield as members in the Drowning Creek Formation. Thus, the Silurian is now divided into what Foerste (1906, p. 62) termed "a great lower division, including chiefly limestone . . . and a great upper division consisting almost entirely of clay." As shown above, his Brassfield–Crab Orchard division was based on his mistaken assumption that the Oldham and the Dayton were equivalent, whereas mapping has shown that the Waco and the Dayton are equivalent. Foerste's lowest-ranking subdivisions, the Plum Creek, Oldham, Lulbegrud, Waco, and Estill, are retained at the member level and are recognizable over most of the area. The Estill is a shale member of the Alger Shale south of Fleming County, as it was used by Foerste (1906, p. 59–60), and is raised to the rank of formation in Fleming and Lewis Counties, where the two other members of the Alger have been removed from it. Formational rank for the Estill was first suggested, although applied to the entire outcrop belt, by Rexroad and others (1965, p. 23–25).

The Noland Formation of Rexroad and others (1965, p. 14–17), named for exposures in the Panola Quadrangle, Madison County, Ky., was not found to be useful in the recent USGS–KGS mapping project. In most of Fleming and Lewis Counties, the base of the Noland (herein the base of the Plum Creek Shale Member of the Drowning Creek) is faunally defined (at the top of the "bead bed"); in most of the rest of the outcrop belt, the top of the Noland (herein the top of the Waco Member of the Alger) is faunally defined. In most of the area these faunal horizons proved not to be mappable. Moreover, the Noland in most of the outcrop belt includes within it the major lithologic change in the Brassfield–Crab Orchard sequence, as shown above.

"The Belfast bed" of Foerste (1896, p. 164) is not used in this report because of confusion over its identification and extent. As stated above (see p. 12), Rexroad and others (1965) applied the name well beyond Foerste's usage of it, as in the type Brassfield section in Madison County; however, their usage implied either an inability to recognize it or a discontinuous distribution of the unit, inasmuch as in many intervening stratigraphic sections it is not listed. O'Donnell (1967) indicated that the "Belfast bed" of Ohio pinches out north of the Ohio River and does not appear in Kentucky, but Rexroad (1967, p. 3) and Childs (1969) used the name from Ohio southward to the type section of the Brassfield. In part, because of this lack of clear definition, the term "Belfast bed" was not used in the mapping program. The inconsistent application of the term, as shown above, also detracts from its value as a stratigraphic unit, and it is not used herein.

The Crab Orchard Formation of Linney (1882) is expanded as a group name for the entire section of interbedded dolomite and shale formerly encompassed by both the Brassfield and Crab Orchard Formations and now by the Drowning Creek Formation and the Alger Shale (or Estill Shale). This serves to unify this essentially continuous depositional sequence and distinguish it from the overlying Bisher Dolomite, which appears to represent a basically different depositional regime, as discussed below.

These nomenclatural revisions serve two important purposes: they produce better agreement between stratigraphic nomenclature and map units used in the mapping program and they place the definitions of the units on a lithologic basis. In the first case, the named or revised formations (Drowning Creek, Alger, Estill) are reflected by actual mapped contacts on 20 of the 31 quadrangle maps in which they occur, and they could have been used on all of the remaining ones, while the Brassfield–Crab Orchard contact was mapped in only 7 of 34 quadrangles in which it occurs, and the "Noland-Estill" contact (herein top of the Dayton Dolomite Member) in only 9 of 30. Moreover, mapping of the Brassfield could conceivably have been extended to a maximum of about 26 quadrangles, and the "Noland" to no more than 1 or 2 additional quadrangles. In the second case, placement of the formational boundaries at lithologic breaks, rather than paleontologic, will avoid the confusion caused by application of the same names to different sequences. For example, while Foerste (1935, p. 125) and Rexroad and others (1965) use the "bead bed" as the top of the Brassfield, Summerson (1963) uses the base of the Dayton, O'Donnell (1967) uses the top of the Dayton (or Waco), Calvert (1968) apparently uses an oolitic iron-ore bed, as does Perry (1962) in the subsurface, while Horvath (1967) uses the "bead bed" at the surface and a lithologic break in the subsurface, and Childs (1969) rejects the "bead bed" in outcrop for a lithologic contact as done herein. These various usages would, at the Concord section in Lewis County (pl. 1), place the Brassfield top at no less than four different horizons, differing by as much as 28 ft in a section in which the entire Drowning Creek Formation does not exceed 54 ft. Confusion of this type has a devastating effect on the interpretation of isopach maps and on paleogeographic reconstructions.

Age and Correlation

An exact age designation for the Silurian units has presented a number of problems because of inconclusive fossil evidence and, more recently, a shift from the North American provincial series to the European standard series (fig. 16).

Foerste (1906, p. 18) originally considered the Brassfield to be Clinton (basal Niagaran, or early Middle Silurian) in age, and the overlying Crab Orchard to be Rochester (Middle Silurian). He later listed the Brassfield and the Plum Creek in the "Medinan" series (Lower Silurian, later revised to Albion) (Foerste, 1931, p. 173) but eventually removed the Plum Creek, placing it back into the Clinton (Foerste, 1935, p. 189). These age assignments were based on fossil identifications, which have been summarized by Foerste (1931). On the basis of conodont studies, Branson and Branson (1947) transferred both the Oldham and the Plum Creek back into the Lower Silurian. Clearly, no consensus ever existed as to the exact position of the Lower-Middle Silurian boundary. This boundary was consequently not shown on the columnar sections of most of the quadrangle maps produced during the USGS–KGS mapping program, but a few of the reports show it at the top of the Plum Creek Shale Member of the Crab Orchard Formation.

Current designations of the age of the Silurian formations are shown in figure 16. The ages indicated by Rexroad and Nicoll (1971, 1972) and Liebe and Rexroad (1977) are based on conodont studies, while those of Berry and Boucot (1970) rely mainly on brachiopods. No physical evidence exists for a significant hiatus anywhere within or at the base of the Silurian, although there is some evidence of minor erosion (locally derived pebbles) at the base of the Brassfield in a few outcrops near Berea (Weir, 1976). Gray and Boucot (1972) present evidence of shallowing water in latest Ordovician time followed by deepening water in the Silurian, which they regard as indicating a paraconformity at the systemic boundary. Sweet (1979), on the basis of conodont studies, shows the uppermost Ordovician to be missing. The hiatus shown between the "Noland Formation" and the Estill Shale on the first three nomenclature columns in figure 16 is based on the supposed absence of conodont Zone II of Walliser (Rexroad and others, 1965, p. 24), and the hiatus shown at the base of the Silurian is presumed because of the thinness of the lower part of the conodont Zone I (Rexroad, 1967). Later discovery of Zone II conodonts (Rexroad, 1970, p. 92) removes the support for the first hiatus, and lack of data on rates of deposition makes it difficult to evaluate the second. Thus, no significant break can be demonstrated in Silurian deposition, as shown in the right-hand column of figure 16, which is, in part, based on conodont data obtained during the mapping program (pl. 2) and, in part, on a reinterpretation of the adjacent columns. On the basis of all of the conodont data, the Brassfield Member of the Drowning Creek of eastern Kentucky is restricted to the lower Llandoverian, and strata of middle Llandoverian Age, placed in the Brassfield by Berry and Boucot (1970), are here regarded as those constituting the upper part of the Drowning Creek. The Brassfield of Ohio, Indiana, and western Kentucky as used by Rexroad (1967), Berry and Boucot (1970), and Peterson (1981), which is characterized by the presence of the brachiopod *Microcardinalia triplesiana* (Rexroad and others, 1965, p. 12; Rexroad, 1967, p. 12; Berry and Boucot, 1970, p. 127), thus includes beds younger than those of the Brassfield at the type section, where *Microcardinalia* occurs in the Oldham Member of the Drowning Creek. These relationships, illustrated in figure 17, suggest that "Brassfield," as used elsewhere in the Cincinnati Arch region (and, according to Berry and Boucot (1970, p. 127), southward into Tennessee and Alabama), is roughly equivalent in age to the combined Brassfield and Oldham Members of the Drowning Creek Formation in eastern Kentucky and thus, in effect, to the Drowning Creek. The intercalated shale members, the Plum Creek and the Lulbegrud, are apparently not represented in outcrop west of the Cincinnati Arch. The Lulbegrud pinches out northward near the Ohio River, while the Plum Creek continues northward in the subsurface into the Michigan basin as the "Cabot Head Shale," with the underlying Brassfield passing into the "Manitoulin Dolomite" (Horvath, 1967). Thus, the common reference to northward thickening of the Brassfield or encroachment of the Brassfield sea (Rexroad and others, 1965, p. 13; Rexroad, 1967, p. 15; Horvath, 1970, p. 34) is, in fact, a migration upward of the top of the Brassfield by definition, based in part on the migration upward of the distinctive crinoid columnals used as the upper boundary, the "bead bed." The Brassfield–Drowning Creek interval may thus be of about the same age throughout the Cincinnati Arch area.

Regional correlations of the Silurian are illustrated in figure 18. The dolomite facies represented by the Drowning Creek Formation in eastern Kentucky ex-

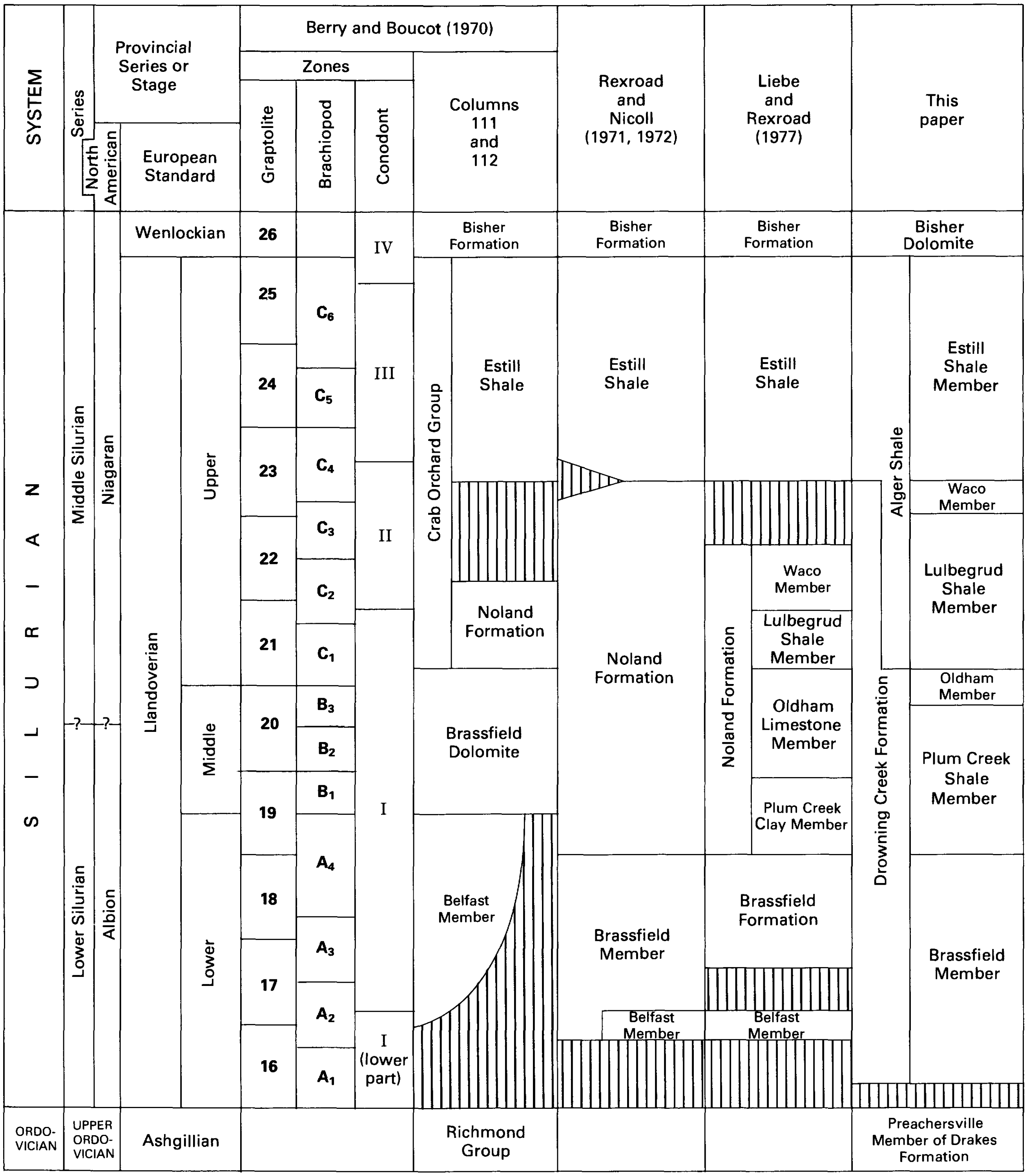

FIGURE 16.—Age of Silurian stratigraphic units in east-central Kentucky as assigned by various authors and in this paper. Assignments of Berry and Boucot (1970) are based on brachiopods; all others, on conodonts. Conodont Zone I, *Distomodus Kentuckyensis;* Zone II, *Pterospathodus celloni;* Zone III, *P. amorphognathoides.* Note: Klapper and Murphy (1974, fig. 10) have placed the base of the *amorphognathoides* zone (Zone III) at the base of brachiopod zone C_6.

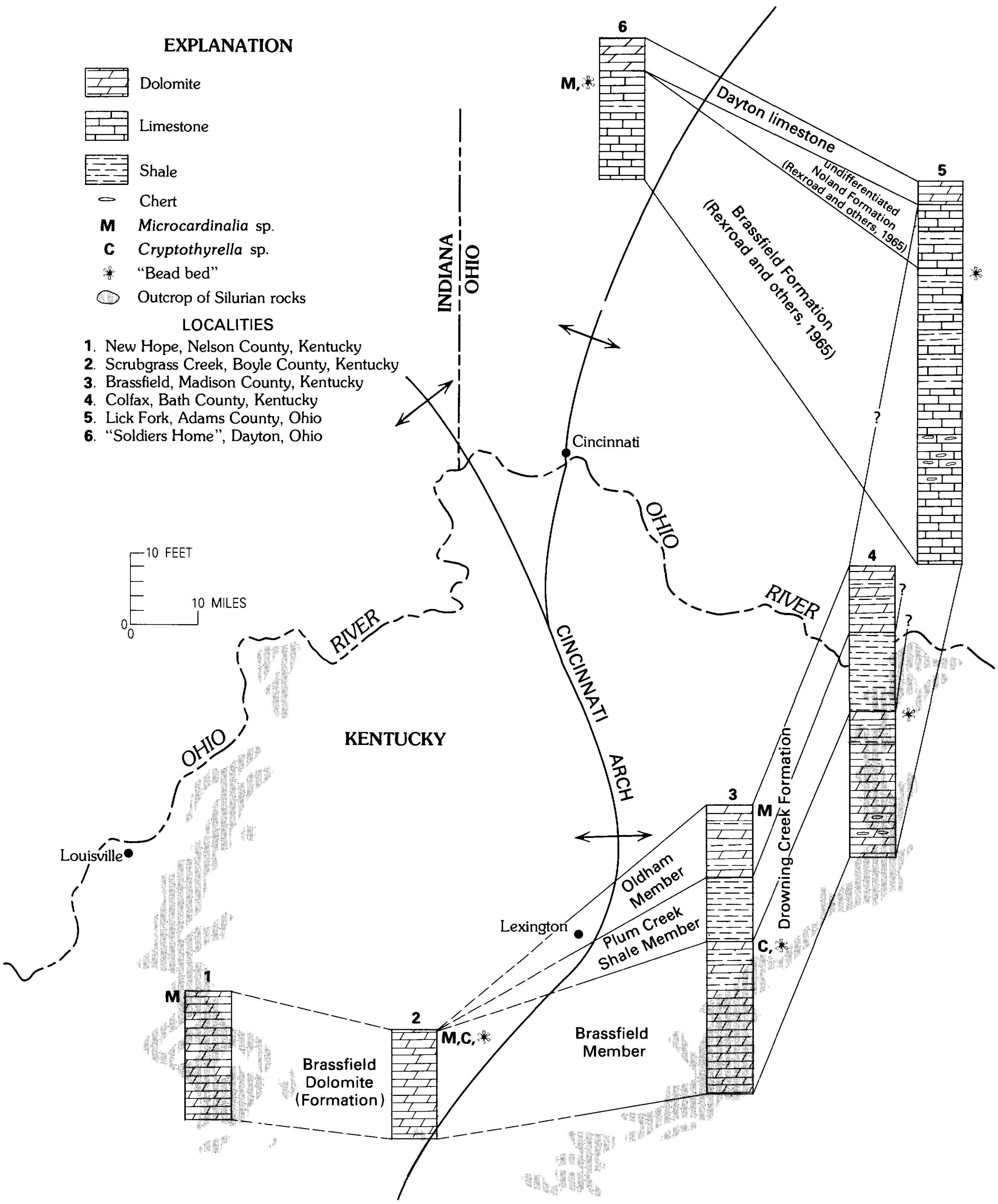

FIGURE 17.—Relationship of Drowning Creek Formation in eastern Kentucky to its probable equivalents in western Kentucky (Brassfield Dolomite Formation) and southern Ohio (Brassfield Limestone and Dayton Limestone). Based in part on data from Foerste (1906, 1935), Rexroad (1967), and Rexroad and others (1965).

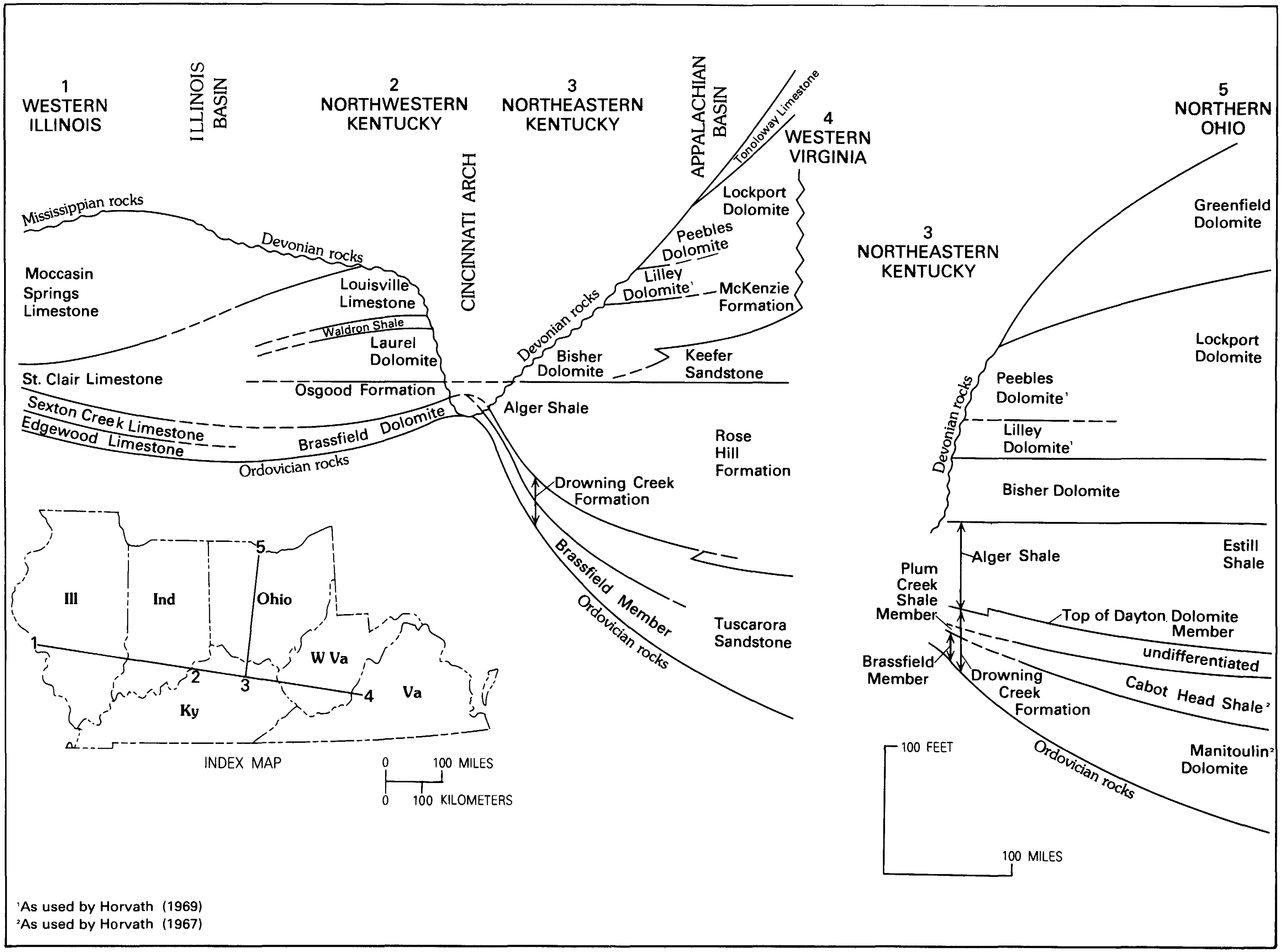

FIGURE 18.—Probable regional correlations. Based on Berry and Boucot (1970) and on correlations suggested by Perry (1962) and Horvatch (1967, 1969). Datum is based of Wenlockian (base of Bisher and Laurel Dolomites).

tends westward into western Kentucky and Indiana (as the Brassfield Dolomite Formation) but grades into limestone northward in Ohio and eastern Indiana (O'Donnell, 1967, fig. 11). These carbonate rocks interfinger eastward with a thickening clastic sequence in the Appalachian basin (Perry, 1962; Horvath, 1967). The Bisher Dolomite, however, represents the lower part of a thicker and more extensive blanket of carbonate deposits represented by the "lower Lockport-McKenzie" unit and younger dolomites (with the underlying Keefer Sandstone) of the Appalachian basin (Horvath, 1969) and by the Laurel Dolomite and younger carbonate rocks to the west (Berry and Boucot, 1970).

Fauna

Fossils other than conodonts identified from collections made during the USGS–KGS mapping program are listed in table 3. These collections are now located in the U.S. National Museum.

Two conodont collections were examined and numerous specimens identified by John W. Huddle during the mapping. The collections were made by J. H. Peck at the Colfax Section and G. C. Simmons at The Bend section (see fig. 2) from all of the units in the Crab Orchard Group. They yielded conodonts characteristic of Zones I, II, and III of Walliser, as shown in Berry and Boucot (1970) (J. W. Huddle, written commun., 1967). These collections have been reexamined for this study and the discrete element taxonomy of Huddle revised to a multielement taxonomy by A. G. Harris of the U.S. Geological Survey. The results are shown in a distribution chart (pl. 2).

Early work on the paleontology of the Silurian in Kentucky was summarized, with extensive fossil lists, by Foerste (1931), and more recent work on conodonts has been reported by Rexroad (1967, 1970) and Cooper (1975).

Environments of Deposition

The extensive thin dolomite units, commonly with abundant shelly marine fossils, suggest deposition in broad shallow seas. Diagenesis and dolomitization have removed many of the original features from these beds, but certain traits remain, especially fossils, so that depositional environments can be interpreted.

Gray and Boucot (1972) report the presence of spore tetrads and other microfossils in the lowermost part of the Brassfield ("Belfast bed") in Adams County, Ohio, indicating a near-shore shallow marine environment. Successive appearance of the Brachiopod communities *Cryptothyrella, Platymerella,* and *Microcardinalia* indicate a progressive deepening of the Drowning Creek Formation, according to the analysis of these communities by Ziegler and others (1968). This progression would extend from the low intertidal zone (*BA* 2) to the subtidal zone (*BA* 4) of Boucot (1975). Harrison and

TABLE 3.—*Silurian fossils other than conodonts identified during the mapping program*

Fossil	Stratigraphic unit	Locality	Collector	Identified by
Brachiopoda:				
Cryptothyrella sp.	Brassfield Member of Drowning Creek Formation.	Palmer quadrangle	G. C. Simmons	A. J. Boucot
Trimerus sp.	Bisher Dolomite	Concord quadrangle	R. H. Morris	R. J. Ross, Jr.
Dalmanites sp.	do	do	do	do
Bumastus sp.	do	do	do	do
Atrypa "reticularis"	do	Palmer quadrangle	G. C. Simmons	A. J. Boucot
"Dolerorthis" flabellites	do	do	do	do
Platystrophia? sp.	do	do	do	do
Gastropoda:				
Platyceros (Platyostoma) cf. *P. niagarense* Hall	Waco Member of Alger Shale.	Panola, Union City, Hedges quadrangles.	G. C. Simmons	E. L. Yochelson
Graptolithina:				
Climacograptus cf. *C. scalaris* (Linné)	Plum Creek Shale Member of Drowning Creek Formation.	Colfax quadrangle	J. H. Peck	W. B. N. Berry

Harrison (1975) described a diminutive ("depauperate") fauna from the Brassfield in Adams County, Ohio, similar to that of the Upper Ordovician Maquoketa Shale of Illinois, Iowa, and Missouri, which they suggest indicates a near-shore warm marine environment with a carbonate mud substrata and moderate current activity, which on the evidence of symmetrical ripple marks and the occurrence of disarticulated right and left bivalve shells in approximately equal proportions, was probably oscillatory. The abundance of fossils (mainly brachiopods, horn corals, bryozoans, and echinoderm fragments), the presence of glauconite and ferruginous zones, and the occurrence of pararipples and small-scale scours indicate a shallow marine platform.

Horvath (1970) described the Silurian of southern Ohio in terms of sedimentary cycles. He considered the Brassfield–Plum Creek sequence transgressive and the Oldham–Lulbegrud regressive, with this cycle repeated for the Dayton (Waco) and Estill. On the other hand, O'Donnell (1967, p. 118) considered the Plum Creek and Lulbegrud Shale Memers regressive and the Oldham and Waco Members transgressive. The pre-Bisher Silurian (herein the Crab Orchard Group), considered as a whole, is a sequence of alternating carbonate and shale deposition, with carbonate decreasing in amount upward and shale increasing. This suggests a progressive deepening of the basin, with intermittent pauses in either the increase in depth or the supply of clastic sediment or both.

The Bisher Dolomite, with its coarse fossil fragments and abundant crossbedding, probably indicates a return to shallower conditions with stronger currents.

Seslavinskii (1978, fig. 4) shows this region during the Silurian to have been in an arid belt just south of the Equator. Whether the regional dolomitization of the Silurian carbonate rocks is the result of such climatic conditions, of "biotic dolomitization" as hypothesized by Boucot (1975, p. 284–286), or of some other mechanism is not known. Table 1 illustrates a northward gradation in the eastern Kentucky Silurian belt from dolomite to limestone. The distribution of these lithofacies for the entire Cincinnati Arch area, shown by O'Donnell (1967, fig. 11), appears to be unrelated to the arch.

Age of the Cincinnati Arch

The Cincinnati Arch was present before deposition of the youngest Devonian strata in Kentucky, as shown by the overstepping of truncated Silurian beds by the Middle Devonian Boyle Dolomite and New Albany–Ohio–Chattanooga Shales of Middle and Late Devonian and Early Mississippian age. Weir and others (1979), in a study of Upper Ordovician lithofacies in Kentucky, found no evidence of the arch in Late Ordovician time. Therefore, folding must have begun at some time within the Early Silurian to Middle Devonian.

The exact time of the initiation of the Cincinnati Arch has been considered by a number of workers. Foerste (1904, p. 338) suggested that the initial stages in its formation "probably preceded Devonian time," since it was already developed by the time of Middle Devonian deposition. He later indicated that it dominated the distribution of Silurian faunas of Kentucky and may have already existed in "Medinan" (Early Silurian) time (Foerste, 1931, p. 174), although isolated remnants of the Brassfield near the axis of the arch, such as at Jeptha Knob (near Shelbyville) and Scrub Grass Creek (near Mitchellsburg), suggest that the formation originally extended across the arch (Foerste, 1935, p. 125, 127). Freeman (1951, p. 9) says that the arch "began to assert itself" as an influence on sedimentation soon after Brassfield deposition, but O'Donnell (1967, p. 116–118) reports no evidence for existence of the arch and indeed, several lines of evidence that suggest it was either not present or ineffective as a barrier to sedimentation through the time of the deposition of the Waco Member of the Alger Shale.

Previous isopach maps of the Silurian (for example, Freeman, 1951, fig. 5; O'Donnell, 1967, fig. 6) generally show, not the original thickness of the units, but the present thickness, which reflects both pre-Devonian truncation and post-Paleozoic erosion. Such maps naturally indicate progressive thickening of the Silurian in all directions away from the arch. In contrast, quadrangle mapping has shown that the variations in thickness of the Brassfield Dolomite (Formation) in outcrop west of the arch in Kentucky are unrelated to the present axis of the arch (McDowell and Peterson, 1980). An isopach map of the Drowning Creek Formation (fig. 19), based on data from localities where the unit is not truncated by erosion surfaces, shows progressive thickening eastward away from the arch. This can also be seen in the stratigraphic sections (pl. 1). The relationship, as illustrated in figure 17, suggests that the axis in central Kentucky, later to mark a major regional arch, began in Early Silurian time as a hinge line. Faulting of the Silurian prior to deposition of the Middle Devonian Boyle Dolomite near Richmond, Ky., reported by Simmons (1966), is the earliest tectonic event known to have affected the Silurian rocks on the east side of the Cincinnati Arch apart from the eastward subsidence. Peterson (1981) presents evidence for minor local tectonic movement during Brassfield time west of the arch. Clearly, tectonic activity was a factor in Kentucky during the Silurian.

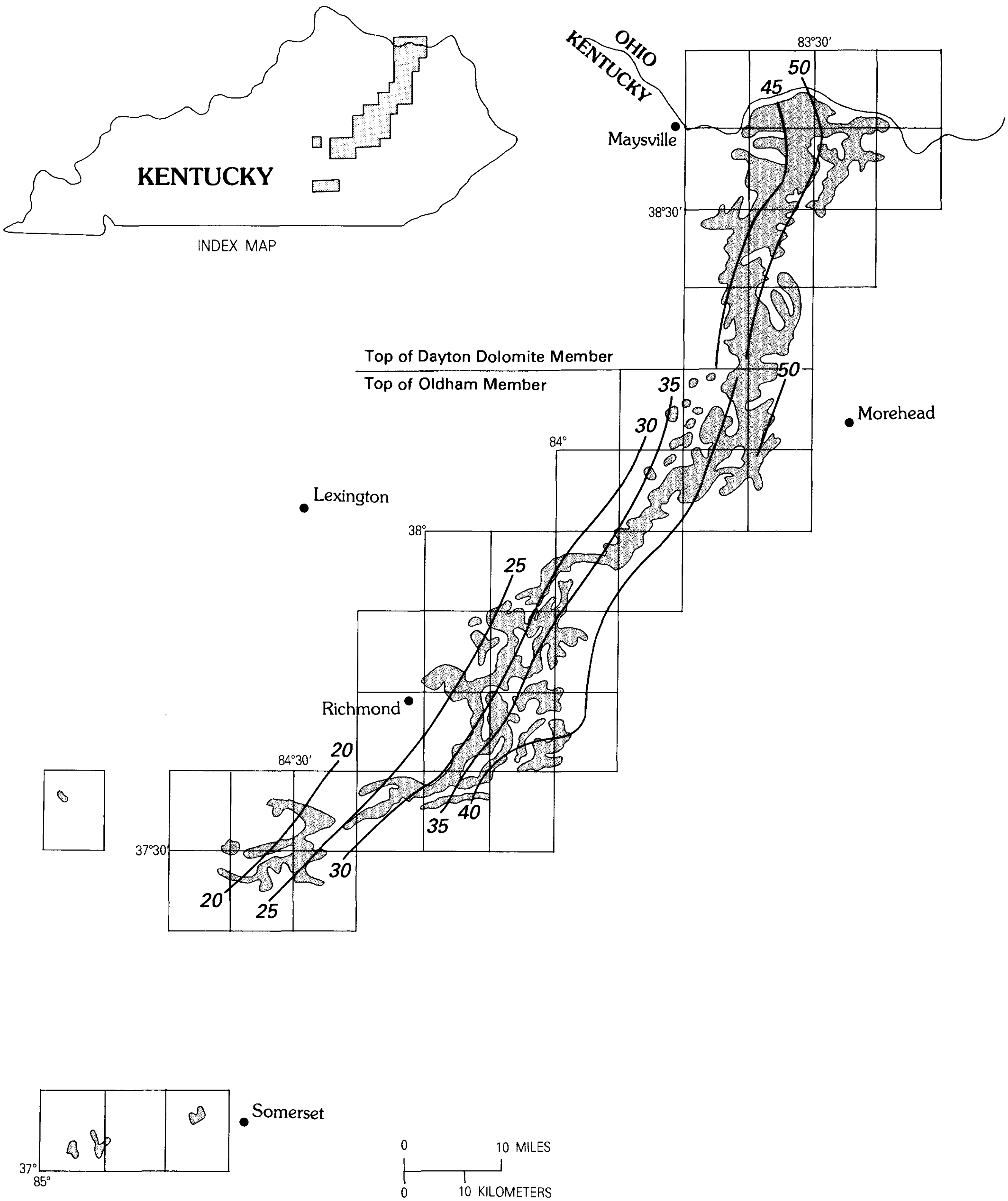

FIGURE 19.—Isopach map showing the Drowning Creek Formation, based on measured sections. Contour interval is 5 ft.

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