Lithostratigraphy of the Silurian Rocks Exposed on the West Side of the Cincinnati Arch in Kentucky

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1151-C

Prepared in cooperation with the Kentucky Geological Survey

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By WARREN L. PETERSON

CONTRIBUTIONS TO THE GEOLOGY OF KENTUCKY

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A description of the five formations of Early and Middle Silurian age and a brief discussion of depositional environments and tectonic history

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LITHOSTRATIGRAPHY OF THE SILURIAN ROCKS EXPOSED ON THE WEST SIDE OF THE CINCINNATI ARCH IN KENTUCKY

By WARREN L. PETERSON

ABSTRACT

This report discusses the Silurian rocks that crop out in Kentucky west of the axis of the Cincinnati arch. The Silurian System has a maximum thickness in this outcrop area of about 190 feet. It is in most places separated from the underlying Ordovician System by a minor erosional unconformity. It is separated from the overlying Devonian System by a major erosional unconformity along which the entire Silurian section has been removed in some areas. The Silurian is divided into five formations, which are, from lowest to highest: (1) Brassfield Dolomite (or Formation), composed of dolomite in the south and both limestone and dolomite in the north; (2) Osgood Formation, shale and minor dolomite; (3) Laurel Dolomite, dolomite; (4) Waldron Shale, shale and minor dolomite; and (5) Louisville Limestone, calcitic dolomite and dolomitic limestone. The Brassfield is of Early Silurian age; the other formations are Middle Silurian.

The main outcrop area of the rocks considered in this report extends about 85 miles south from the Ohio River and has a maximum width of about 20 miles. The rocks in this belt generally dip westward about 30 feet per mile. Part of this dip was imparted to the rocks prior to the cutting of the overlying unconformity, but most of it came later. Minor tectonic movement along west-northwest and east-northeast trends probably took place during Silurian time. Thickening of the Brassfield and Osgood southward across the west-northwest-trending Bardstown monocline and thickening of the Brassfield in the axial zone of the east-northeast-trending Lyndon syncline indicate that movement took place along these structures during or immediately before the deposition of these formations.

Several remarkably persistent thin units of dolomite and shale that make up the Osgood, the Laurel, and the Waldron indicate a depositional strike about north. The dolomite was originally mostly fossiliferous limestone deposited in shallow marginal seas. The source of the shale was to the east.

INTRODUCTION

This report summarizes information on the Silurian rocks of Kentucky that crop out on the west side of the Cincinnati arch; the information was acquired during the geologic mapping of 7½-minute quadrangles by the U.S. Geological Survey, in cooperation with the Kentucky Geological Survey, between 1961 and 1978. The Silurian rocks in the subsurface are not considered here. The most comprehensive discussion of the Silurian rocks in the subsurface of Kentucky was given by Freeman (1951). Although the Silurian outcrop extends northward into Indiana and southward into Tennessee, these areas are not discussed. A summary of the ages of Silurian formations exposed in Kentucky and correlations of these formations with units in surrounding regions, along with discussions of the Silurian System in North America, were given by Berry and Boucot (1970).

This report considers the distribution, thickness, lithology, petrography, and surface expression of each mapped stratigraphic unit. It also briefly discusses depositional environments and the influence of tectonism on the deposition of the Silurian rocks in the study area. Three measured sections and a list of sections that were well exposed in 1978 are included at the end of the report.

The Silurian rocks described in this report crop out in 38 quadrangles, as shown in figure 1 and plate 1. The geologic maps of these quadrangles are listed in table 1. They show the outcrop areas in much greater detail than figure 1 and plate 1 and present detailed rock descriptions and structural information. The distribution of Silurian rocks is also shown in greater detail on the new "Geologic Map of Kentucky" (McDowell, Grabowski, and Moore, in press).

Isopach maps of the main outcrop belt are shown on plate 1 (pt. B); they were made from field measurements in the Maud, Bardstown, Cravens, Lebanon Junction, St. Catharine, Loretto, New Haven, and Nelsonville quadrangles and in other quadrangles from thicknesses read off the geologic quadrangle maps by using topographic contours. The isopach maps of the Osgood Formation and Laurel Dolomite (pl. 1, pt. B, 4, 5) were not completed for the northern part of the main outcrop belt because the variation in thickness is so small that thickness trends could not be established by this technique. For the same reason, the isopach map of the Waldron Shale is incomplete except for the zero contour.

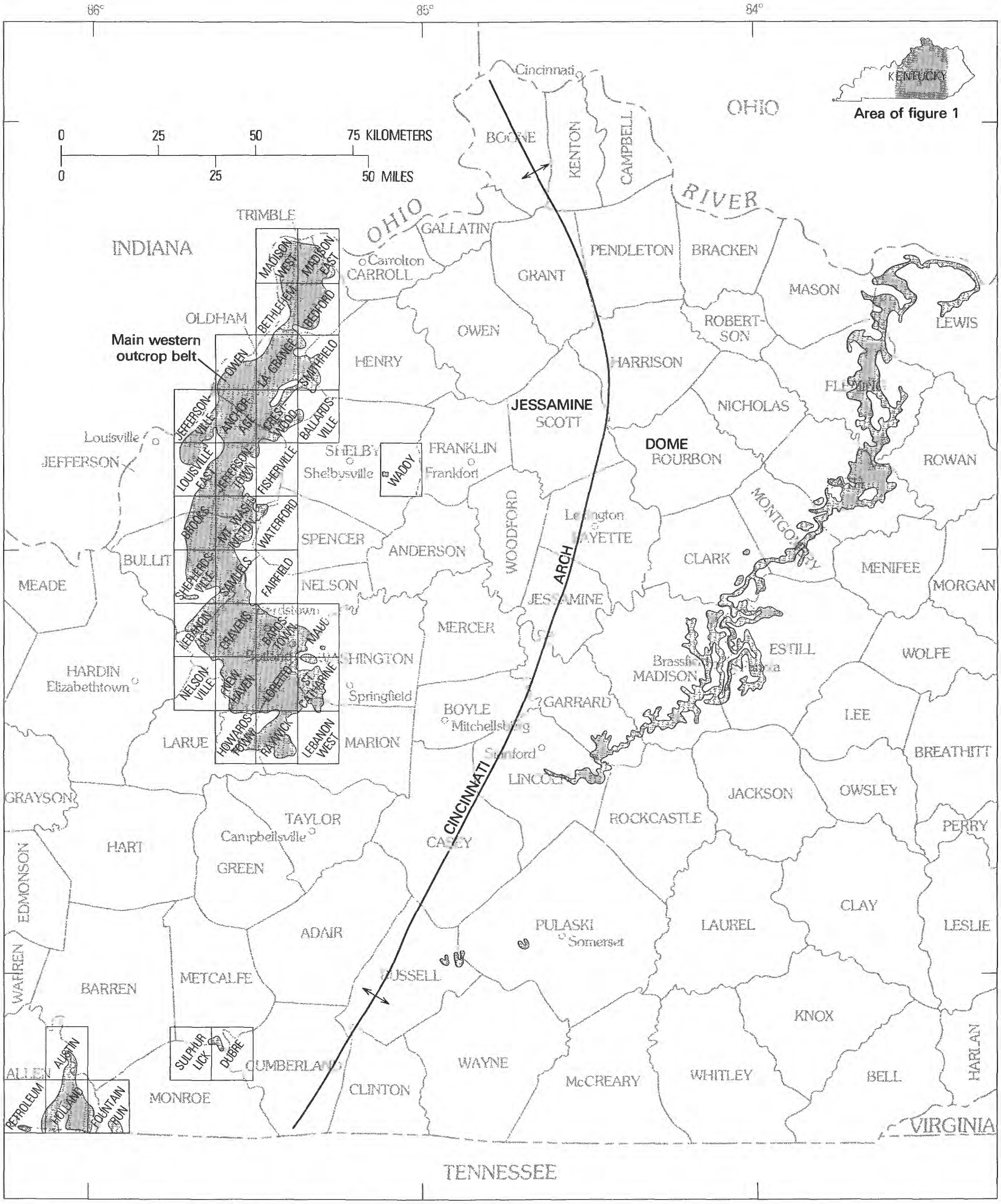


FIGURE 1.—Index map of central Kentucky showing counties, outcrop areas of Silurian rocks, and 7½-minute quadrangles containing Silurian rocks west of the Cincinnati arch. Outcrop area east of the arch is generalized from the "Geologic Map of Kentucky" (Kentucky Geological Survey, 1954). Outcrop area west of the arch and that near Somerset is generalized from recent geologic quadrangle maps (table 1).

TABLE 1.—*List of the geologic quadrangle (GQ) maps (all at scale 1:24,000) published by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey for the 38 quadrangles discussed in this report*

Quadrangle	GQ No.	Date of publication	Author(s)
Anchorage	906	1971	Kepferle, R. C., Wigley, P. B., and Hawke, B. R.
Austin	173	1961	Moore, S. L.
Ballardsville	1389	1977	Kepferle, R. C.
Bardstown	825	1969	Peterson, W. L.
Bedford	1409	1977	Swadley, W C
Bethlehem	1436	1977	Swadley, W C
Brooks	961	1972	Kepferle, R. C.
Cravens	737	1968	Peterson, W. L.
Crestwood	1342	1976	Kepferle, R. C.
Dubre	676	1967	Lewis, R. Q., Sr.
Fairfield	1225	1975	Peterson, W. L.
Fisherville	1321	1976	Kepferle, R. C.
Fountain Run	254	1963	Hamilton, Warren
Holland	174	1962	Nelson, W. H.
Howardstown	505	1966	Kepferle, R. C.
Jeffersontown	999	1972	Moore, F. B., Kepferle, R. C., and Peterson, W. L.
Jeffersonville	1211	1974	Kepferle, R. C.
La Grange	901	1971	Peterson, W. L., Moore, S. L., Palmer, J. E., and Smith, J. H.
Lebanon Junction	603	1967	Peterson, W. L.
Lebanon West	1509	1978	Moore, S. L.
Louisville East	1203	1974	Kepferle, R. C.
Loretto	1034	1972	Peterson, W. L.
Madison East	1471	1978	Gibbons, A. B.
Madison West	1469	1978	Swadley, W C
Maud	1043	1972	Peterson, W. L.
Mount Washington	1282	1976	Kepferle, R. C.
Nelsonville	564	1966	Peterson, W. L.
New Haven	506	1966	Peterson, W. L.
Owen	904	1971	Peterson, W. L., and Wigley, P. B.
Petroleum	352	1964	Myers, W. B.
Raywick	1048	1973	Kepferle, R. C.
St. Catharine	1252	1975	Peterson, W. L.
Samuels	824	1969	Kepferle, R. C.
Shepherdsville	740	1968	Kepferle, R. C.
Smithfield	1371	1977	Luft, S. J.
Sulphur Lick	323	1964	Harris, L. D.
Waddy	1255	1975	Cressman, E. R.
Waterford	1432	1977	Luft, S. J.

Plate 2 shows a line of sections extending northward from the Raywick quadrangle to the Madison West quadrangle. The diagrammatic sections do not represent actual measured sections nor do they indicate that the rocks are actually exposed at the points shown on the index map (pl. 2, inset); rather, they are generalized representations of what is present in the vicinity of the points and were mostly taken from the columnar sections shown on the geologic quadrangle maps. Actual measured sections are not portrayed because thick well-exposed sections are commonly not available; Silurian sections must, therefore, be pieced together from widely scattered outcrops.

Insoluble-residue determinations were made on 18 samples of Silurian carbonate rocks by dissolving the crushed rock in warm hydrochloric acid. Calcium and magnesium percentages were also determined for the same samples by versenate titration (Guerrero and Kenner, 1955). Percentages of calcite and dolomite were calculated by assuming that all magnesium was from dolomite and all calcium was from dolomite or calcite. The results of the analyses and calculations are shown in table 2.

Thin sections were cut from 30 samples of carbonate rock, including the samples listed in table 2. The slides are composed mostly of a mosaic of fine carbonate crystals in which the dolomite could not generally be distinguished visually from the calcite. Calcite, however, must be present because virtually all samples effervesce, at least weakly, in dilute hydrochloric acid, and calculations based on chemical analyses indicate calcite to be present. The thin sections were not stained to separate calcite from dolomite because in the writer's experience, staining does not successfully differentiate calcite from dolomite in finely crystalline rock.

Descriptive information concerning the Silurian rocks in the area covered by this report was given by Butts (1915), McFarlan (1943), Browne and others (1958), Nosow (1959), O'Donnell (1967), Rexroad (1967), Nicoll and Rexroad (1968), and Gauri and others (1969). Browne and others (1958) and Nosow (1959) included several lithologic sections. Fossils in Jefferson County were listed by Butts (1915). Fossils from Jefferson, Bullitt, and Oldham Counties were identified by Browne and others (1958). Conodonts were identified by Rexroad (1967) and Nicoll and Rexroad (1968).

"Fine," "medium," and "coarse" are used here to designate grains and crystals having the same particle size as the fine, medium, and coarse sand sizes of the Wentworth (1922) scale. "Very fine," when used to refer to crystal size, indicates particle size corresponding to the silt or very fine sand sizes of the Wentworth scale, which the writer finds difficult to distinguish under the hand lens. In the petrographic descriptions, "crystal" is used to designate a mineral particle that has formed in place, such as a dolomite rhomb, and "grain" is used to designate a sedimentary particle. "Grain" is also used for particles that are of uncertain origin or that are probable aggregates of crystals.

AREAS OF SILURIAN OUTCROP

The Silurian rocks in Kentucky crop out mainly in narrow arcuate belts east and west of the Jessamine dome (fig. 1). A few small isolated exposures have been found in areas of strong structural dis-

TABLE 2.—*Measured percentages of insoluble residue, calcium, and magnesium; calculated percentages of calcite and dolomite; and calculated Ca/Mg ratios for 18 samples of Silurian rocks*

[Insoluble-residue percentages were determined by dissolving rock in warm HCl; calcium and magnesium percentages were determined by versenate titration (Guerrero and Kenner, 1955); calcite and dolomite were calculated by assuming that all calcium and magnesium were from calcite and dolomite and that all magnesium was in dolomite. Determination of percentages of insoluble residue, calcium, and magnesium and calculation of Ca/Mg ratios by Robert F. Gantnier, U.S. Geological Survey]

Formation	Sample No.	Location	Rock type and position within formation	Insoluble residue (percent)	Ca (percent)	Mg (percent)	Calcite (percent)	Dolomite (percent)	Sum*	Ca/Mg ratios
Louisville Limestone	LO3	1	Dolomite, 10.3 ft above base of formation.	8.3	19.4	10.6	4.7	80.6	93.6	1.11
	LO2	1	Dolomite, 7.8 ft above base of formation.	3.7	20.5	11.5	3.7	87.4	94.8	1.08
	LO1	2	Dolomite, 2.4 ft above base of formation.	1.6	22.5	11.4	9.1	88.6	99.3	1.20
Laurel Dolomite	L5	3	Dolomite, upper part of quarry stone, 24 ft below top of formation.	9.3	21.7	9.8	13.7	74.5	97.5	1.34
	L4	4	Dolomite, typical bed of quarry stone, 7.4 ft above base of quarry stone.	2.0	22.5	8.4	21.5	63.8	87.3	1.63
	L3	4	Dolomite, vuggy zone, 2 ft below base of quarry stone.	12.5	21.8	11.7	6.2	88.9	107.6	1.13
	L2	4	Dolomite, vuggy zone, 4.2 ft above shale bed.	1.6	22.6	10.8	11.9	82.9	96.4	1.27
	L1	4	Dolomite, from lower part below shale bed, 6.7 ft above base of formation.	7.5	20.4	9.5	11.8	72.2	91.5	1.30
Osgood Formation	O2	5	Dolomite, very argillaceous, 0.25 ft above base of formation.	25.2	16.8	9.5	2.8	72.2	100.2	1.07
	O1	5	Dolomite. argillaceous, 0.6 ft above base of formation.	18.0	18.3	9.0	8.5	68.4	94.9	1.23
Brassfield Formation	B8	6	Limestone, yellowish-brown typical of the formation.	1.2	39.3	.5	96.1	3.8	101.1	47.70
	B7	7	Dolomite, finely crystalline, 0.9 ft above base of formation.	9.5	21.3	9.6	13.6	73.0	96.1	1.35
	B6	7	Dolomite, medium crystalline, 0.5 ft below top of formation.	6.5	22.4	9.3	17.6	70.7	94.8	1.46
Brassfield Dolomite	B5	8	Dolomite from evenly bedded upper part, 1 ft below top of formation.	11.1	19.4	8.7	12.6	66.1	89.8	1.35
	B4	8	Dolomite from evenly bedded upper part, 3.7 ft below top of formation.	7.0	19.5	9.4	9.9	71.4	88.3	1.26
	B3	8	Dolomite from irregularly bedded middle part, 10.1 ft above base of formation.	8.3	23.7	9.1	21.6	69.2	99.1	1.58
	B2	8	Dolomite from irregularly bedded middle part, 7 ft above base of formation.	4.1	21.8	8.7	18.6	66.1	88.8	1.52
	B1	8	Dolomite from massive-weathering laminated lower part, 1.7 ft above base of formation.	14.3	20.2	8.4	15.8	63.8	93.9	1.46

* Sum of percentages of insoluble residue, calculated calcite, and calculated dolomite.

LOCATIONS

1. Cravens quadrangle; roadcut on south side of the Blue Grass Parkway about ⅝ mile west of Snake Run.
2. Cravens quadrangle; first roadcut west of Snake Run on north side of the Blue Grass Parkway.
3. Cravens quadrangle; roadcut on south side of the Blue Grass Parkway about ¾ mile west of Snake Run.
4. Cravens quadrangle; first roadcut on north side of the Blue Grass Parkway west of the bridge across the Beech Fork.
5. Cravens quadrangle; first roadcut on south side of the Blue Grass Parkway, just west of the bridge across the Beech Fork.
6. Jeffersontown quadrangle; roadcut on south side of U.S. Interstate Highway 64, 40 yards west of the Jefferson Freeway.
7. Jeffersontown quadrangle; roadcut on north side of U.S. Interstate Highway 64, 50 yards west of the Jefferson Freeway.
8. Cravens quadrangle; first roadcut on south side of the Blue Grass Parkway west of the bridge across the Beech Fork; same roadcut as pictured in figure 4A.

turbance within the Ordovician rocks that crop out on the dome. Small areas of outcrop are present also at or near the bottoms of deep valleys south of the main areas of outcrop (fig. 1). This report deals with the Silurian rocks west of the axis of the Cincinnati arch except for one small outcrop area near Mitchellsburg, Ky. (shown on fig. 1), which is excluded because the Silurian rock cropping out there seems more like that found east of the axis than that found to the west.

SILURIAN SYSTEM IN THE MAIN WESTERN OUTCROP BELT

DISTRIBUTION

The main outcrop belt of Silurian rocks, referred to as the main western outcrop throughout the remainder of this report, is about 85 miles long, south to north, in Kentucky and has a maximum width of about 20 miles. The formations dip to the west at an average of about 30 feet per mile (pl. 1, pt. B, 1). To the east, they have been removed by erosion. The outcrop belt continues northward beyond the Ohio River into Indiana. At the southern end of the main western outcrop belt, in the southern part of the Raywick and Lebanon West quadrangles, the Silurian rocks have been truncated eastward toward the axis of the arch by pre-Middle Devonian erosion and are buried by younger sediments to the south and west.

CONTACTS

A minor erosional unconformity, marked primarily by an irregular surface having a maximum local relief of about 2 feet, is present at the base of the Silurian System north of about the northern border of the Samuels quadrangle and south of about the southern border of the New Haven quadrangle (see pl. 2, sections 1 and 8–15). The thickness of the Ordovician rocks removed is not known but seems not to have been more than a few feet. No angular discordance is apparent. South of the northern border of the Samuels quadrangle and north of the southern border of the New Haven quadrangle, the contact is nearly planar (figs. 4*A*, 4*B*, and 6*C*). In part of this area, a laminated dolomite bed less than 1 foot thick is overlain by a shale bed about 1 to a few inches thick at the top of the Ordovician. The nearly planar top of this couplet is interpreted to mean that little or no erosion took place immediately prior to the deposition of the lowermost Silurian strata (Brassfield Dolomite).

According to Rexroad (1967), the Silurian strata unconformably overlie the Ordovician strata throughout the main outcrop belt. As stated above, the abrupt and nearly planar contact in part of the area does not appear to be erosional; however, a hiatus of considerable magnitude could presumably be present.

The Silurian is separated from the overlying Devonian rocks by a major erosional unconformity (pl. 2) that has in places removed the entire Silurian section at the southern end of the main outcrop belt (fig. 2). The Devonian rocks immediately above the unconformity are younger (Middle Devonian) in the southern part of the main outcrop belt and older (Early Devonian) in the northern part, north of about the middle part of the Louisville East quadrangle (fig. 3, pl. 2).

The Beechwood Member of the Sellersburg Limestone, which overlies the Silurian south of the Jeffersontown quadrangle, is rarely more than 4 feet thick; the same unit is called the Boyle Limestone on the Raywick and Lebanon West geologic quadrangle maps (table 1). The unconformity almost nowhere has any local relief. The lack of relief, together with the persistent thinness of the overlying unit, indicates that the unconformity was a relatively level surface having only minor topographic relief at the time of the deposition of the overlying Beechwood.

THICKNESS

An isopach map of the total thickness of Silurian rocks in the main western outcrop belt is shown on plate 1 (pt. B, 2). The maximum thickness is about 190 feet in the southern part of the Brooks quadrangle. The thickness decreases rather uniformly to the north but is quite variable to the south. Most of the variation in the total thickness of the Silurian has been caused by erosion prior to the deposition of the Devonian sedimentary rocks. Eastward, from the west border of the Lebanon West quadrangle, the Silurian rocks were totally removed by the pre-Middle Devonian erosion.

DESCRIPTION OF SILURIAN FORMATIONS IN THE MAIN WESTERN OUTCROP BELT

The Silurian in the main western outcrop belt is divided into five formations. From the lowest to the highest they are: (1) Brassfield Dolomite (Formation), (2) Osgood Formation, (3) Laurel Dolomite, (4) Waldron Shale, and (5) Louisville Limestone. All five formations are present in the northern part of the main western outcrop belt. The higher formations have been progressively eliminated from the section toward the south by erosion along the overlying unconformity (pl. 2, fig. 2).

The nomenclature used on the geologic quadrangle maps listed in table 1 is essentially that used by Butts (1915) in Jefferson County, Ky., with one minor change which is discussed in the Definition of the Osgood Formation (see also fig. 3). Of the formations exposed on the west side of the Jessamine dome, only one, the Brassfield, is also recognized on the east size (McFarlan, 1943, p. 35).

BRASSFIELD DOLOMITE (FORMATION)

DEFINITION

The Brassfield Limestone was named by Foerste (1905, 1906). The type section is along the abandoned Louisville and Atlantic Railroad between Brassfield and Panola in Madison County, Ky., where the Brassfield consists of 18 to 19.5 feet of dolomite and minor shale. It can be traced westward from the type area but is eliminated at the unconformity at the base of the Devonian near the crest of the Cincinnati arch. Except for a small outlier in Scrubgrass Creek Valley, near Mitchellsburg, Ky. (Foerste, 1906, 1935; Moore, 1978), it has not been found in an outcrop between the eastern edge of the Lebanon West quadrangle and Stanford, Ky. (fig. 1).

The unit is designated the Brassfield Dolomite where it is composed almost entirely of dolomite, south, west, and east of the Samuels quadrangle. In the Samuels quadrangle and north, the Brassfield is composed of both dolomite and limestone and is designated the Brassfield Formation. The Brassfield is thus divided geographically into two lithologic parts, herein referred to as the southern and northern facies.

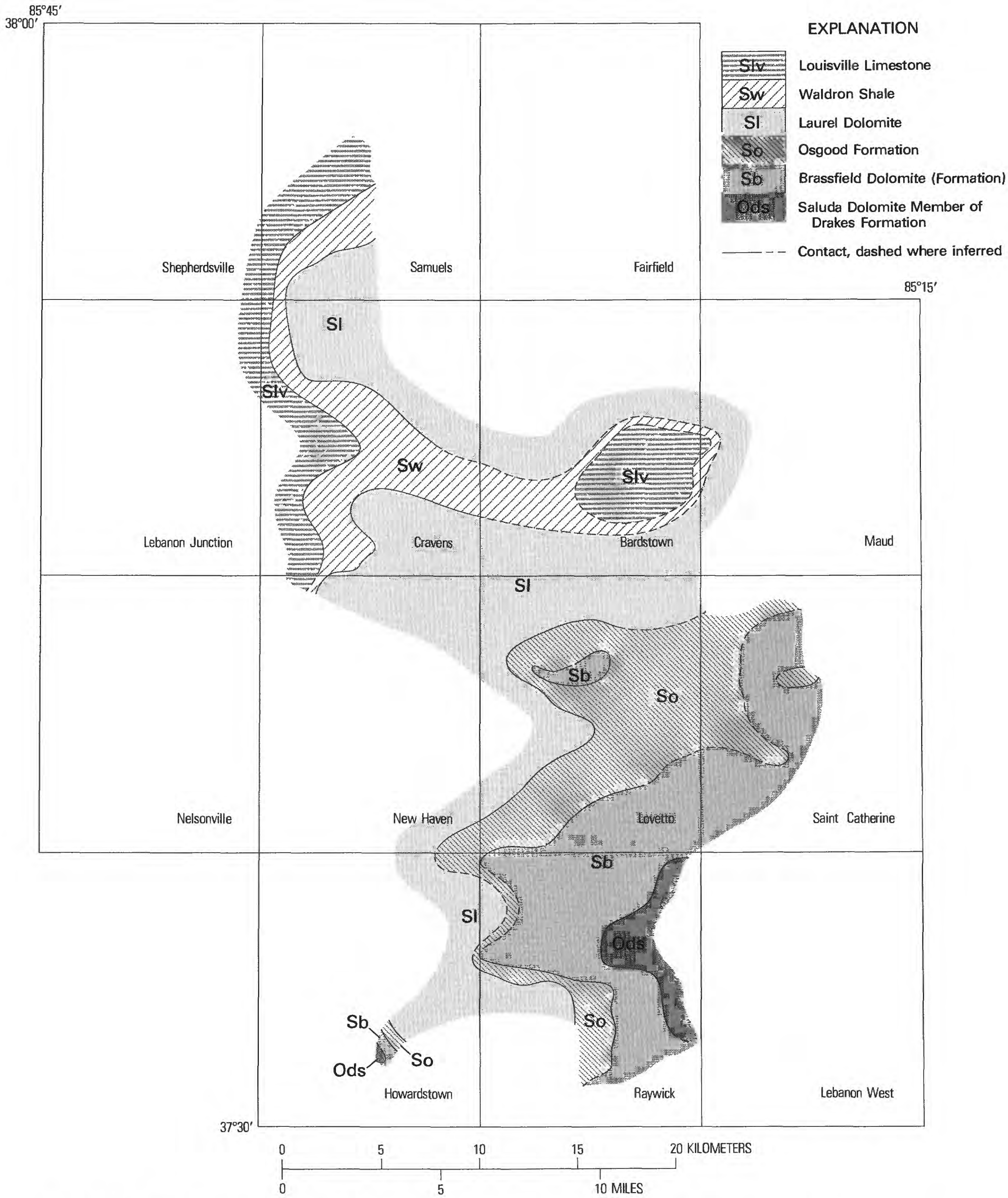


FIGURE 2.—Paleogeographic map depicting the unconformity below the Middle Devonian rocks in the southern part of the main western outcrop belt. Overlying formation is the Beechwood Member of the Sellersburg Limestone in all quadrangles except the Raywick and Lebanon West where it is the Boyle Limestone. North of the area shown here, the unconformity is on the Louisville Limestone.

SYSTEM	SERIES	Bardstown quadrangle (Peterson, 1969)		Anchorage quadrangle (Kepferle and others, 1971)		Jefferson County (Butts, 1915)	
DEVONIAN	Upper and Middle Devonian	New Albany Shale		New Albany Shale		New Albany Shale	
	Middle Devonian	Sellersburg Limestone	Beechwood Limestone Member	Sellersburg Limestone	Beechwood Limestone Member	Sellersburg Limestone	Beechwood Limestone Member
					Silver Creek Limestone Member		Silver Creek Limestone Member
	Middle and Lower Devonian			Jeffersonville Limestone		Jeffersunville Limestone	
SILURIAN	Upper Silurian						
	Middle Silurian	Louisville Limestone		Louisville Limestone		Louisville Limestone	
		Waldron Shale		Waldron Shale		Waldron Shale	
		Laurel Dolomite		Laurel Dolomite		Laurel Dolomite	
						Osgood Formation	Upper shale
							Upper limestone
		Osgood Formation		Osgood Formation			Lower shale
							Lower limestone
	Lower Silurian	Brassfield Dolomite		Brassfield Formation		Brassfield Limestone	
ORDOVICIAN	Upper Ordovician	Drakes Formation	Saluda Dolomite Member	Drakes Formation	Saluda Dolomite Member	Saluda Limestone	Hitz Member

FIGURE 3.—Diagram showing nomenclature of stratigraphic units used on the geologic quadrangle maps in the main western outcrop belt and those used by Butts (1915) in Jefferson County, Kentucky.

The Brassfield extends southward from the area discussed here into central Tennessee (Wilson, 1949) and northward into southern Indiana (French, 1967).

EXTENT AND THICKNESS

The distribution of the Brassfield Dolomite (Formation) and the thickness ranges recorded on the various geologic quadrangle maps are shown on plate 1 (pt. A, 3). An isopach map is shown on plate 1 (pt. B, 3). The Brassfield is thickest in the southern part of the Bardstown quadrangle, where it reaches a maximum of at least 27 and possibly 30 feet. North of the southwestern part of the Samuels quadrangle, the Brassfield thins rather abruptly toward the northeast, the unit being about 21 feet thick in the southwestern part of the Samuels quadrangle and about 5 feet thick in the northeastern part (Kepferle, 1969). In most areas north of the 10-foot isopach shown on plate 1 (pt. B, 3) the thickness is probably 2 to 3 feet, and in some small areas (not shown on pl. 1 because these areas are not shown on the geologic quadrangle maps), the Brassfield is missing. The Brassfield has also been reduced in thickness or completely cut out by pre-Middle Devonian erosion (pl. 1, fig. 2) south of the southern border of the Bardstown quadrangle.

CONTACTS

The Brassfield is underlain in the main western outcrop belt by the Saluda Dolomite Member of the Drakes Formation (Upper Ordovician). The nature of the contact is discussed above. The Brassfield is overlain everywhere in the outcrop area by the Osgood Formation except at the southern end of the belt where it is unconformably overlain by the Beechwood Member of the Sellersburg Limestone or the equivalent Boyle Limestone (fig. 2, pl. 2).

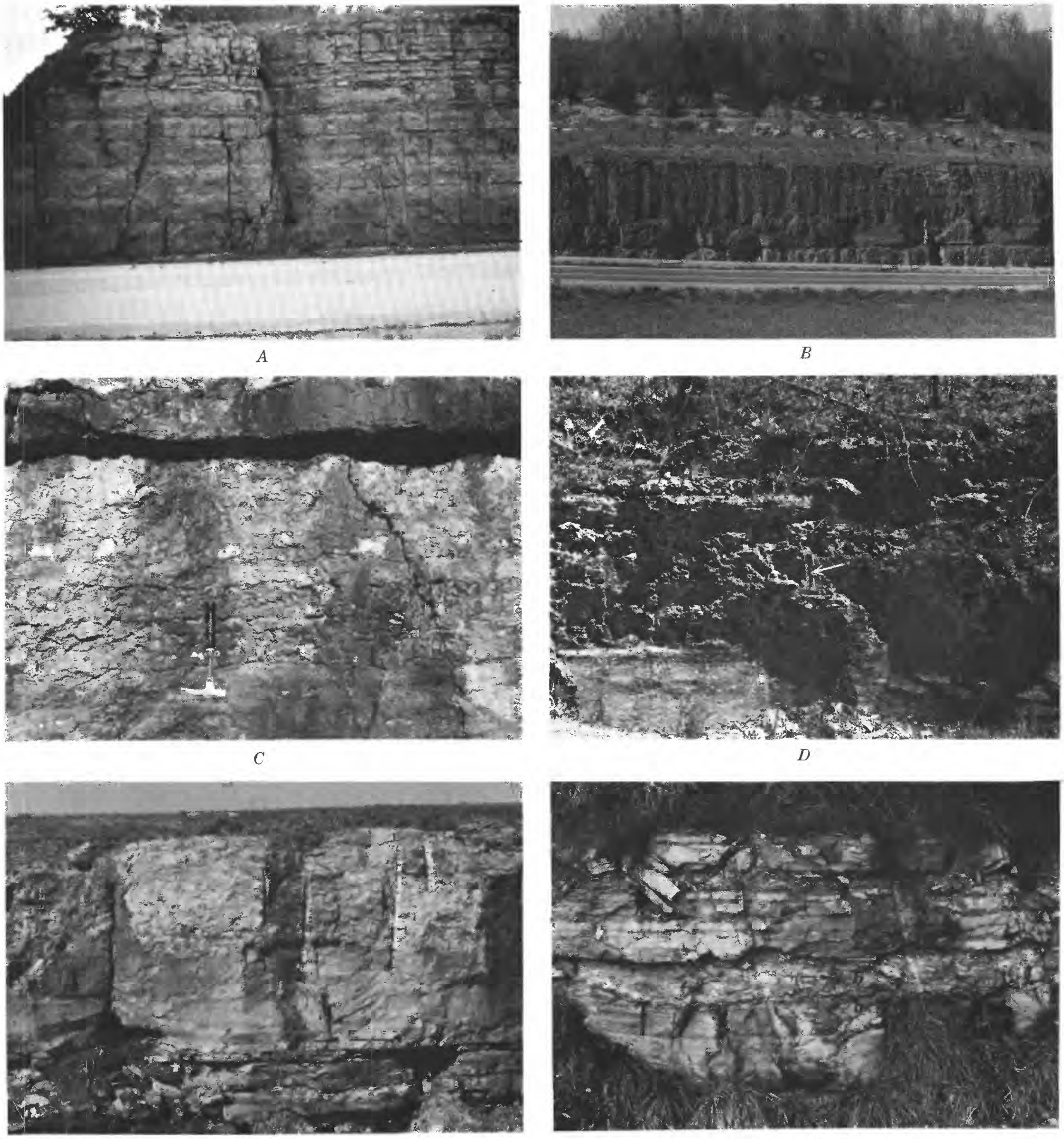
SOUTHERN FACIES

LITHOLOGY

South of the northern part of the Samuels quadrangle, the Brassfield is composed of dolomite, chert, and minor shale. The dolomite is various shades of gray where fresh: it weathers yellowish gray, brown, and grayish orange. The weathered rock is commonly mottled or speckled. The dolomite is very fine to medium crystalline and appears to contain ghosts of calcite grains that were much larger than the present crystals. It is somewhat calcitic and effervesces weakly in dilute hydrochloric acid. Glauconite is abundant. Pyrite is common in small single crystals and small irregular aggregates. Clear calcite crystals, as much as 1 inch across, form irregular masses as much as 6 inches across. Some of these calcite masses near Bardstown are bordered by sphalerite. Fossils are sparse to abundant, generally indistinct, and poorly preserved. Fossils include brachiopods, crinoid columnals, horn corals, and colonial corals. Chert is present as nodules and irregular beds 1 to 2 inches thick; it is gray where fresh and weathers dull white. Much of it contains abundant silicified fossils. Chert is most abundant in the middle part of the unit and probably nowhere makes up more than 5 percent of the unit.

In the Bardstown and Cravens quadrangles, the Brassfield consists of three parts (figs. 4*A*, *B*). At the base is a massive-weathering unit, as much as 8 feet thick, made up of irregular laminae ¼ to ½ inch thick. This rock appears to contain ghosts of sand-size calcite grains and may have originally been calcarenite. The middle part (fig. 4*C*) consists of indistinct lumpy beds 1–2 inches thick separated by thin partings of darker and more finely crystalline dolomite; stylolites are common. This part appears to contain ghosts of a poorly sorted skeletal hash. The upper few feet consists of even beds 2–12 inches thick that have slightly irregular tops and bases. These beds are locally separated by shale partings, particularly in the upper 2 feet. They appear to contain ghosts of a well-sorted sediment, possibly a fine-grained calcarenite.

FIGURE 4.—Photographs of the Brassfield Dolomite (Formation). *A*, Exposure showing (*a*) lower part, composed of deformed dolomite laminae; (b) middle part, composed of deformed and disrupted very thin dolomite beds; and (*c*) upper part, composed of even thin dolomite beds. Calcite aggregates and chert lenses and nodules are abundant in middle part. Black rod in lower left is 4 feet long. Basal contact of the Brassfield is 2 inches above base of rod; Saluda Dolomite Member of the Drakes Formation is below. Top of exposure is top of the Brassfield, which here is 25 feet thick. Roadcut along south side of Blue Grass Parkway, Cravens quadrangle, just west of the Beech Fork. *B*, Brassfield Dolomite (*b*), underlain by the Saluda Dolomite Member of the Drakes (*a*) and overlain by the Osgood Formation (*c*), which is overlain by the basal part of the Laurel Dolomite (*d*). Note planar base of the Brassfield and the thin dolomite bed at the top of the Saluda. Brassfield is 23 feet thick; same exposure as described in measured section no. 1 (p. C24–C25). Roadcut along south side of Blue Grass Parkway just east of the bridge across the Beech Fork, Bardstown quadrangle. *C*, Exposure of the middle part of the Brassfield, composed of distorted and disrupted dolomite beds, overlying the lower part, composed of distorted dolomite laminae. Light areas are aggregates of coarse calcite crystals. Roadcut along U.S. Highway 150, just east of Mill Creek, Bardstown quadrangle. *D*, Middle part of the Brassfield, showing vuggy weathered surface for comparison with the fresher surface shown in figure 4*C*; lower part of photograph shows massive-weathering laminated part. Roadcut along county road 500 feet north of Bear Creek and 1,800 feet east of the Beech Fork, Bardstown quadrangle. *E*, Brassfield Formation, overlying the Hitz Limestone Bed of the Saluda Dolomite Member of the Drakes; contact at *c* is a stylolite. Lower 21 inches of the Brassfield is a finely crystalline dolomite; overlying 29 inches is grayish orange and very fossiliferous spar-cemented calcarenite containing irregular lumps and lenses of finely



A B C D E F

FIGURE 4.—Continued.

crystalline dolomite and many stylolites; upper 6 inches is finely crystalline dolomite; uppermost inch or 2 inches of the Brassfield is missing. Roadcut at intersection of Jefferson Freeway (Kentucky Highway 841) and Kentucky Highway 155, Jeffersontown quadrangle. *F*, Exposure of uppermost part of the Saluda Dolomite Member of the Drakes (*a*), Brassfield Formation (*b*), and dolomite at the base of the Osgood Formation (*c*). Brassfield is 11 inches thick; basal contact is a stylolite. Brassfield is yellowish-brown to grayish-orange coarse-grained limestone containing thin wispy beds of greenish-gray dolomite. Basal part of the Osgood is 3 feet 2 inches thick and is composed of medium-gray to yellowish-gray finely crystalline dolomite. Roadcut along the north side of the westbound lanes of U.S. Highway I-71 at the east border of the Anchorage quadrangle.

This three-fold subdivision of the Brassfield has not been recognized outside the Bardstown and Cravens quadrangles. In the Raywick quadrangle, beds are irregular and commonly are 2–5 inches thick (Kepferle, 1973).

PETROGRAPHY

Five thin sections were cut from Brassfield Dolomite samples taken from the roadcut in the Cravens quadrangle shown in figure 4*A*. All samples effervesce weakly in dilute HCl and contain more calcium than magnesium as shown in table 2 (samples B1–B5). Calcite, however, could not generally be distinguished from the dolomite in thin sections.

A thin section from the lower, massive-weathering part (table 2, sample B1) shows a mosaic of carbonate crystals 30–100 μm across, which average about 50 μm across, and scattered pores 50–300 μm across (fig. 5*A*). Many of the crystal contacts are planar. The slide contains pyrite in grains 20 to 50 μm across, unidentified opaque grains (which may be altered pyrite) that are 10 to 20 μm across, and sparse silt-size quartz grains. Two thin sections were cut from the middle, irregularly bedded part (table 2, samples B2 and B3). They show a mosaic of carbonate crystals 50 to 200 μm across that average about 125 μm across (fig. 5*B*). Sparse pyrite is present in irregularly shaped crystals or aggregates of crystals as much as 1 mm across. Sparse silt-size grains of quartz and glauconite are present. One slide contained a layer 2 mm thick consisting of subhedral to euhedral carbonate crystals 30 to 70 μm across, abundant silt-size quartz grains, pyrite grains 10 to 50 μm across, and unidentified opaque grains of similar size. This layer is apparently the darker dolomite forming the partings that are in the middle part of the Brassfield in the Bardstown and Cravens quadrangles (unit 8 of measured section 1 on p. C25).

Two sections were cut from the upper, even-bedded part (table 2, samples B4 and B5). They show a mosaic of carbonate crystals 30 to 100 μm across, similar to that shown in figure 5*A*. These slides contain sparse silt-size quartz, very sparse glauconite, and sparse unidentified opaque grains (which may be altered pyrite) about 20 μm across.

OUTCROP

The southern facies of the Brassfield is very well exposed and forms conspicuous ledges, especially along gully sides. Pits characterize the weathered surface of the unit, especially the middle part (fig. 4*D*). Chert rubble litters the outcrops and is found as float on fields and hillsides.

NORTHERN FACIES

North of the northern border of the Samuels quadrangle, the Brassfield Formation is composed of limestone, dolomite, and minor chert. Limestone and dolomite are both interbedded and intermixed. The formation is lithologically variable and the reader is directed to the various geologic quadrangle maps (listed in table 1) for detailed descriptions. The limestone (figs. 4*E*, 4*F*) is mostly yellowish gray or yellowish brown and weathers grayish orange. It is composed of abundant whole and fragmentary fossils in a medium- to coarse-grained fossil-fragmental matrix, all cemented by sparry calcite and forming irregular beds 1 to 4 inches thick. The limestone contains large clear calcite crystals in irregular clots 1 to 6 inches across. Sparse chert is present in thin lenses. Fossils include crinoid columnals, brachiopods, bryozoans, and colonial and solitary corals. Fossils are silicified in some outcrops. A small percentage of the limestone is fine grained and unfossiliferous. Most of the dolomite is yellowish gray to greenish gray, very finely crystalline, in part very thinly laminated, and commonly unfossiliferous (fig. 4*E*). It is present partly in continuous beds but mostly in discontinuous beds 1–2 inches thick and in irregular lenses and masses. A small percentage of dolomite is medium to coarsely crystalline. Both limestone and dolomite contain irregular patches of an unidentified finely crystalline green mineral, very dark green grains of glauconite, and sparse pyrite. The bedding in the Brassfield is in part deformed and disrupted and, in places, has a brecciated appearance.

PETROGRAPHY

DOLOMITE

The following description of dolomite in the Brassfield is based on a study of four thin sections, two from the Jeffersontown quadrangle, one from

FIGURE 5.—Photomicrographs of Silurian rocks. *A*, Brassfield Dolomite, lower massive-weathering laminated part. Mosaic of dolomite and probably calcite containing scattered quartz grains *q*, pores *p*, pyrite, and unidentified opaque grains (may be altered pyrite). Plane light. From roadcut along Blue Grass Parkway as shown in figure 4*A*, 1.7 feet above the base. *B*, Brassfield Dolomite, middle irregularly bedded part. Mosaic of dolomite and probably calcite containing minor silt-size quartz grains *q*. Note that crystal size is much coarser than that shown in figure 5*A*. Plane light. From same roadcut as shown in figure 4*A*, 7 feet above the base. *C*, Limestone from northern facies of the Brassfield Formation. Fossil fragments cemented by sparry calcite; in part replaced by dolomite; *b* is brachiopod, *c* is crinoid columnal, *d* is dolomite rhomb. Crossed nicols. From roadcut at intersection of the Jefferson Freeway (Kentucky Highway 841) and

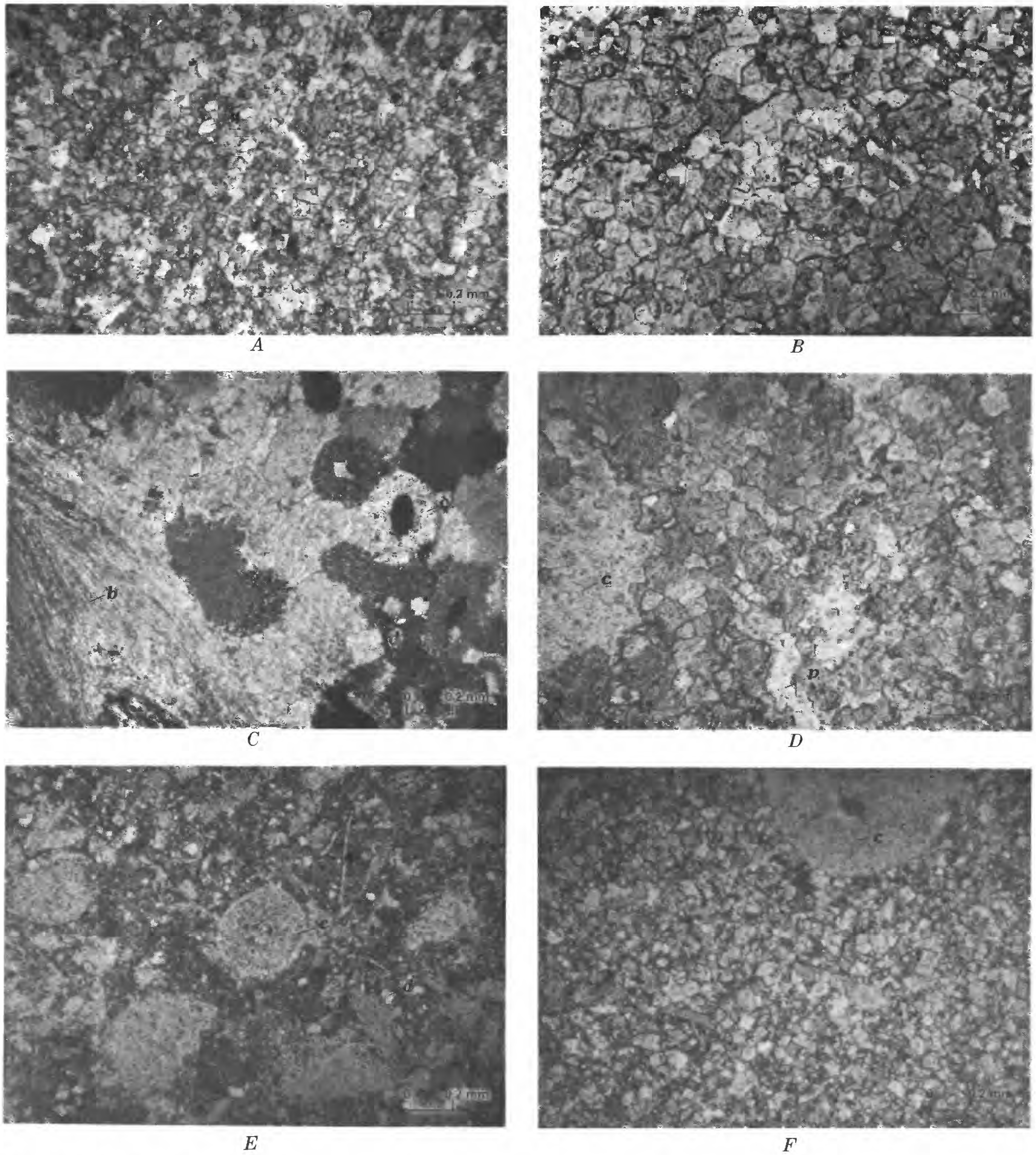


FIGURE 5.—Continued.

Kentucky Highway 155, Jeffersonville quadrangle. *D*, Laurel Dolomite, vuggy zone. Mosaic of dolomite and probably calcite. Partially replaced fossil fragment *c* is probably a crinoid columnal; large pore at *p*. Plane light. First roadcut on north side of the Blue Grass Parkway west of the Beech Fork, Cravens quadrangle. *E*, Louisville Limestone, dolomitic limestone phase. Abundant echinoderm ossicles *c* and other fossil fragments in a matrix of micrite and microspar; scattered rhombs of dolomite *d*. Plane light. Jeffersonville quadrangle, from same exposure as shown in figure 9*B*. *F*, Louisville Limestone, calcitic dolomite phase. Mosaic of dolomite and probably calcite containing interstitial micrite, crinoid columnal *c*, and scattered fossil fragments. Plane light. Jeffersonville quadrangle, from same exposure as shown in figure 9*B*.

the La Grange quadrangle, and one from the Mt. Washington quadrangle. All samples apparently contain calcite because they effervesce weakly in dilute HCl. Chemical analyses of two of the samples (table 2, samples B6 and B7) indicate that calcite is present; however, it could not generally be distinguished from the dolomite in the thin sections, which show a mosaic of carbonate crystals that range in size mostly from 10 to 100 μm. Crystals of the same size tend to cluster together; thus, patches of crystals 20 to 30 μm across are juxtaposed with patches of crystals 30 to 50 or 70 to 100 μm across. Abundant single crystals or aggregates of several crystals as much as 1 mm across are scattered through the slides. The sections also contain a claylike mineral that forms films on the boundaries between carbonate crystals and is more abundant where crystal size is smaller. Pyrite is present in minute cubes (10 μm across) and larger irregular grains. Much of the pyrite is apparently altered to limonite (many of the minute cubes are reddish brown in reflected light). Glauconite grains and silt-size quartz are sparse. The laminations (1–3 mm thick) seen on outcrops appear to be caused by the presence or absence of the claylike mineral or by variation in crystal size.

LIMESTONE

The following description of limestone in the Brassfield is based on a study of three thin sections, all from the Jeffersontown quadrangle. Results of a chemical analysis of one sample (B8) are shown in table 2. In thin section, the limestone consists partly of recognizable fossil fragments cemented by sparry calcite (fig. 5*C*). Fossil fragments are mostly crinoid columnals and other echinoderm fragments 200 to 700 μm across. Fragments of bryozoans and brachiopods are also present. The remainder of each slide is composed of anhedral calcite crystals ⅓ to 1 mm across that have generally irregular boundaries; some crystal contacts appear to be sutured. The slides contain dolomite rhombs 50 to 200 μm across scattered singly or in patches. They also contain very sparse quartz silt and unidentified very fine grained dark material along crystal boundaries. The limestones from which the slides were cut are partially recrystallized fossiliferous calcarenites.

OUTCROP

The Brassfield is well exposed in steep gullies. In many places, it forms a resistant ledge above cliffs, falls, and plunge pools in the underlying Saluda Dolomite Member of the Drakes Formation.

LEE CREEK MEMBER OF NICOLL AND REXROAD (1968)

Nicoll and Rexroad (1968) defined the Lee Creek Member of the Brassfield Limestone, which forms the upper part, or in places, all of the Brassfield in southeastern Indiana. The Lee Creek Member, as defined, is lithologically distinct from the remainder of the Brassfield: "The lower part of the Brassfield is a crystalline limestone that commonly contains abundant fossils. The Lee Creek is a fine-grained sugary dolomite and generally lacks fossils" (Nicoll and Rexroad, 1968, p. 9). This subdivision does not seem to be applicable in Kentucky because the unfossiliferous fine-grained dolomite is found at the top, at the base (fig. 4*E*), and in discontinuous beds and lenses throughout the Brassfield.

OSGOOD FORMATION

DEFINITION

The Osgood Formation (Beds) was named by Foerste (1897) for exposures at Osgood, Ripley County, Ind. As used by Butts (1915) in Jefferson County, Ky., it included a lower dolomite, a lower shale, an upper dolomite, and an upper shale (the dolomite was called limestone by Butts). The upper shale is very thin (commonly less than a foot) and the upper dolomite (commonly a few feet thick) is lithologically similar to the overlying Laurel Dolomite. When mapping of these units began in Kentucky, the upper shale and upper dolomite were included in the Laurel Dolomite because the lower dolomite and lower shale seemed to form a better lithologic unit than all four subdivisions taken together. Consequently, the Osgood Formation as used on the recent geologic quadrangle maps includes only the lower dolomite and lower shale of the Osgood as used by Butts(1915).

In Indiana, the Osgood is now designated the lower member of the Salamonie Dolomite as used by French (1967). The Osgood extends southward from the area considered here into central Tennessee (Wilson, 1949). It correlates approximately with the Estill Shale Member of the Crab Orchard Formation on the eastern side of the Cincinnati arch in Kentucky (Berry and Boucot, 1970).

EXTENT AND THICKNESS

The distribution of the Osgood Formation and the thickness ranges recorded on the various geologic quadrangle maps are shown on plate 1, pt. A, 4, and an isopach map of the formation is shown on plate 1, pt. B, 4. The Osgood is apparently thickest in the Bardstown quadrangle, reaching a thickness of about

50 feet in a small area about 1 mile northwest of Botland. I have measured maximum thicknesses of 40 or more feet in the Bardstown, Maud, Loretto, and New Haven quadrangles. The average thickness, where not affected by pre-Middle Devonian erosion, is probably 30 to 35 feet in this area. Westward from the Bardstown quadrangle, the Osgood is somewhat thinner. For a distance of about 20 miles north of the northern border of the Bardstown quadrangle, the average thickness is about 20 feet. North of the northern border of the Waterford quadrangle, it averages somewhat less. In the southern part of the main outcrop belt, the thickness has been irregularly reduced, and east of the Saint Catharine quadrangle, the formation has been completely cut out by the pre-Middle Devonian erosion (pl. 1, pt. B, 4; fig. 2).

CONTACTS

The Osgood Formation nearly everywhere overlies the Brassfield Formation. In the southern part of the main outcrop belt, the contact appears to be gradational through a few inches to a foot or so by interlayering of thin beds of dolomite and shale, but north of about the southern border of the Mt. Washington quadrangle, the contact is commonly sharp. In the northern part of the main outcrop belt, where the Brassfield is missing in small areas, the Osgood rests on the Saluda Dolomite Member of the Drakes Formation. Rexroad (1967) concluded that the Osgood and the underlying Brassfield are separated by an unconformity, because parts of one or more conodont zones are missing.

LITHOLOGY

The Osgood is composed of shale and dolomite. The shale is mostly greenish gray and weathers yellowish gray. Pale-red layers are present in the shale, particularly in the vicinity of Bardstown, Ky. The shale is most commonly dolomitic. In relatively fresh outcrops, it weathers with a blocky fracture to firm chips and grains and is, in part, better called mudstone. Less commonly, the shale is more clayey and crudely fissile. Both varieties weather to a plastic clay. The clayey shale is more prevalent in the vicinity of Bardstown, Ky., where it occupies the lower three-fourths of the Osgood. In the northern part of the main western outcrop belt, the shale is mostly dolomitic. Fossils are sparse.

The dolomite is greenish gray or yellowish gray and weathers yellowish gray or grayish orange. It is argillaceous, grades into dolomitic shale, and is sparsely fossiliferous. It is present in thin indistinct to distinct beds, 1–3 inches thick, throughout the unit but is more common near the top and base. North of the southern border of the the Mt. Washington quadrangle, dolomite forms a distinct basal unit 1–5 feet thick in many areas. This dolomite is more argillaceous and more finely crystalline than dolomite in the underlying Brassfield. Outcrops of the upper part of the Osgood are shown in figures 6*A* and 6*B*, and an outcrop of the basal dolomite is shown in figure 4*F*.

PETROGRAPHY

Two thin sections were cut from dolomite beds in the basal part of the Osgood, one from the Cravens quadrangle and one from the La Grange quadrangle. These dolomites apparently contain calcite because they effervesce weakly in dilute HCl, and the chemical analyses of samples O1 and O2 (table 2) indicate that calcite is present. The slides show a mosaic of anhedral and subhedral carbonate crystals ranging mostly from 10 to 40 μm across. A claylike mineral is present in thin films along the crystal boundaries. Unidentified opaque grains about 10 μm across are sparse, and silt-size quartz grains are very sparse. The rather large percentages of insoluble material recorded in table 2 must be mostly the claylike mineral.

OUTCROP

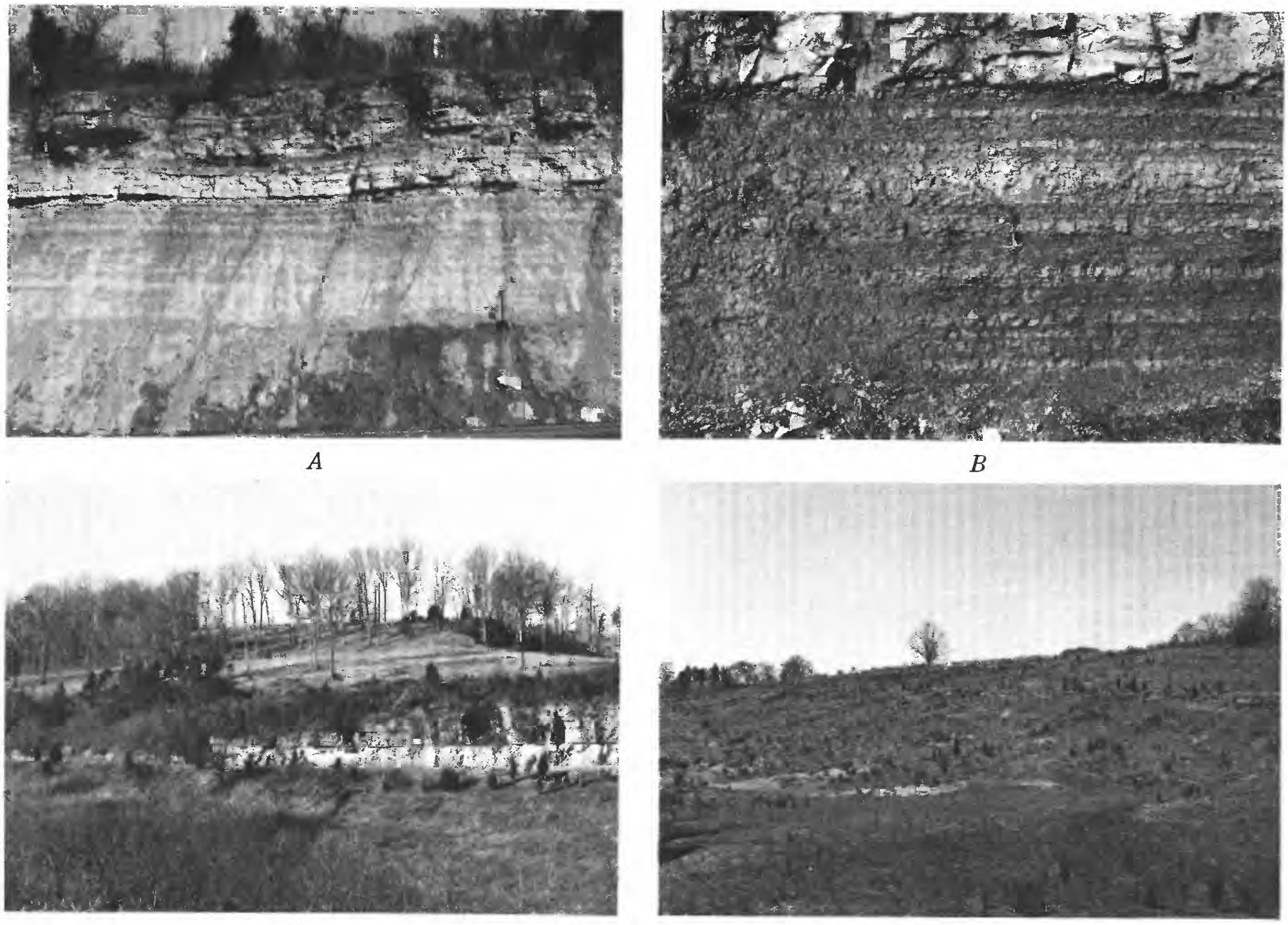
The Osgood is nonresistant and weathers to a plastic clay. The surface is gullied, the soil is thin, and the vegetation is sparse in many places (fig. 6*D*). The Osgood tends to slump and the surface is lumpy and is marked by small slump scarps in many areas. Along valley sides, a bench tends to form on the top of the thin layer of Osgood overlying the Brassfield (fig. 6*C*). Away from the bench, the surface on the Osgood steepens towards the overlying Laurel Dolomite.

LAUREL DOLOMITE

DEFINITION

The Laurel Dolomite was named by Foerste (1896) for exposures in the vicinity of Laurel, Franklin County, Ind. As discussed in the Definition of the Osgood Formation, the upper shale and upper dolomite of the Osgood as used by Butts (1915) in Jefferson County, Ky., have been included in the Laurel on the recent geologic quadrangle maps.

In Indiana, the Laurel is now designated the upper member of the Salamonie Dolomite as used by



A B C D

FIGURE 6.—Photographs of the Osgood Formation. *A*, Exposure showing upper part of the Osgood Formation and basal part of the Laurel Dolomite; contact at *c*. The Osgood in this exposure is mostly faintly bedded dolomitic shale (or mudstone) except for the rib of dolomite about 2 feet below the upper contact; this rib is conspicuous in the area around Bardstown, Ky. Shovel is 3 feet 6 inches long. Roadcut along U.S. Highway 150 just east of Rowan Creek, Bardstown quadrangle. *B*, Exposure showing the upper part of the Osgood and the basal part of the Laurel; contact is at *c*. The faint bedding in the Osgood shale (or mudstone) is produced at least in part by differences in dolomite content. Roadcut along U.S. Highway I-71 on the north side of the westbound lanes at the west border of the Crestwood quadrangle. *C*, View showing the bench that is commonly formed on the Osgood Formation. Lower part of the roadcut is the Saluda Dolomite Member of the Drakes Formation; upper part is the Brassfield Dolomite. The basal part of the Laurel crops out among the trees on the hillside in the background. View looking northwest from the Blue Grass Parkway in the eastern part of the Cravens quadrangle. *D*, Slope formed on the Osgood showing small slumps, gullies, and unvegetated areas. View looking west from U.S. Highway 150 about ½ mile west of Mill Creek, Bardstown quadrangle.

French (1967). The Laurel extends southward from the area considered here into central Tennessee (Wilson, 1949). According to Berry and Boucot (1970), it correlates eastward with the Bisher Limestone (Dolomite) and the Lilley Dolomite of local usage in southern Ohio.

EXTENT AND THICKNESS

The distribution of outcrops of the Laurel Dolomite and the range of thicknesses recorded on the geologic quadrangle maps are shown on plate 1, pt. A, 5; isopachs of the southern part of the belt are shown on plate 1, pt. B, 5. The thickness of the Laurel was measured in several places in the Bardstown and Cravens quadrangles while this report was being written. The maximum thickness found in these quadrangles was 61.5 feet (same location as measured section 2, p. C25–C26). The 77-foot maximum thickness recorded on the geologic map of the Cravens quadrangle (Peterson, 1968) was an error resulting from a structural misinterpretation. The maximum thickness of the Laurel is about 65 feet in the north-central part of the New Haven quadrangle. The Laurel is generally thinner north of the northern border of the Samuels quadrangle (commonly 40–55 feet thick) than it is to the south. In the southern part of the main outcrop belt, the Laurel has been thinned by pre-Middle Devonian erosion, and it has been completely removed from the southernmost part (pl. 1, pt. A, 5; fig. 2).

CONTACTS

The Laurel everywhere overlies the Osgood Formation in the main western outcrop area. The contact is commonly gradational by interlayering of thin shale and dolomite beds through a few inches and possibly as much as 3 feet.

The Laurel is conformably overlain by the Waldron Shale in much of the main outcrop belt. In the southern areas, the Laurel is unconformably overlain by the Beechwood Member of the Sellersburg Limestone or the equivalent Boyle Limestone.

LITHOLOGY

The Laurel is composed of dolomite, minor shale, and sparse limestone. Very sparse chert is found in the northern areas. The dolomite is commonly light gray and weathers yellowish gray, grayish yellow, brown, and orange. The shale is greenish gray and dolomitic.

The Laurel can be divided into six subunits that are remarkably persistent, as shown on plate 2. The subunits are described below from lowest to highest:

(1) Dolomite and minor shale, ranging in thickness from about 1.5 to 10 feet (fig. 7*A*). The dolomite is finely crystalline and porous. It contains small aggregates of clear calcite crystals, abundant molds of crinoid columnals, and ghosts of other fossils; it forms faint to distinct uneven beds 1 to 8 inches thick that are separated in places by shale partings. Weathering causes the unit to have a pitted surface similar to that found on the Brassfield (fig. 4*D*).

(2) A persistent greenish-gray dolomitic clay shale bed ranging in thickness from a few inches to about 3 feet. The bed is rarely exposed, but is presumed to be persistent because of the tendency of large blocks of overlying dolomite to slip away from the outcrop. The reentrant formed by weathering of this bed is shown on figure 7*A*.

(3) Fine to medium crystalline and porous dolomite containing abundant dolomitized crinoid columnals and stems, brachiopods, and fossil fragments. Segregations of clear calcite crystals are sparse. Finely crystalline pyrite is present in small aggregations and also in sparse lenses ¼ to 1 inch thick and several inches to 2 feet wide, parallel to bedding. The subunit ranges in thickness from about 12 feet to as much as 30 feet. Bedding is obscure (fig. 7*C*), and the entire subunit generally weathers as a massive bed (fig. 7*B*) having an extremely pitted surface of fist-size holes separated by partitions of dolomite (fig. 7*D*). This subunit is referred to elsewhere in this report as the "vuggy zone."

(4) Dolomite and minor shale. The dolomite is very finely crystalline (fine silt size), is much less porous than other dolomite in the Laurel, and contains small aggregates of clear calcite crystals, small segregations of finely crystalline pyrite, and scattered glauconite grains. Commonly, it is very sparsely fossiliferous. Some beds contain abundant molds of tiny crinoid columnals and sparse brachiopods. Perfectly preserved casts of trilobites are rarely found. The beds are of even thickness and commonly range in thickness from 4 to 12 inches but locally are as thick as 3 feet (figs. 8*B* and 8*C*). The beds are internally structureless, except for faint laminations that are exaggerated by weathering in places. Commonly, the weathered surface of the dolomite is dense, smooth, and rounded, in striking contrast to the pitted weathered surface of the subunit below. The beds are separated in places by dolomitic shale partings as much as 2 inches thick and locally by stylolites (Kepferle and others, 1971). This subunit has been widely quarried for aggregate, agricultural lime, and building stone. It is referred to elsewhere in this report as the "quarry stone."

(5) Dolomite and minor shale. The dolomite is finely crystalline and porous. It is present in indistinct beds 1 to 6 inches thick that are separated in places by partings of shale (fig. 8*A*). The subunit weathers to a deeply pitted surface similar to that shown in figure 4*D*. It is as much as 14 feet thick in the area around Bardstown, Ky., but thins to the north and south. It has not commonly been reported as a distinct subunit north of the northern border of the Bardstown quadrangle.

(6) Dolomitized oolite containing crinoid columnals and brachiopods and commonly forming a single faintly laminated bed that ranges in thickness from 0 to about 4 feet (fig. 8*A*). The oolites and fossil fragments are completely replaced by porous, finely crystalline dolomite. This subunit is found from the southern limits of outcrop to the outcrop in the southern part of the Crestwood and Anchorage quadrangles.

PETROGRAPHY

The following description of the Laurel Dolomite is based on eight thin sections, six from the Cravens quadrangle and two from the Crestwood quadrangle. Results of chemical analyses of five of the six samples from the Cravens quadrangle are shown in table 2. Samples L1-L4 came from a roadcut along the Blue Grass Parkway about 150 feet from the one pictured in figure 7*A*. All samples effervesce weakly in dilute HCl, and chemical analyses (table 2) indicate that calcite must be present. Generally, however, dolomite could not be differentiated from calcite in the thin sections.

One thin section was cut from the lower dolomite (table 2, sample L1). It shows a mosaic of anhedral to subhedral carbonate crystals measuring mostly 30–100 μm across and abundant irregular pores that are mostly 100 μm to 1 mm across. The slide contains anhedral opaque grains 10–20 μm across that reflect reddish-brown light and may be limonite altered from pyrite. It also contains sparse quartz silt.

Three thin sections were cut from the vuggy zone. Chemical analyses of two of these samples from the Cravens quadrangle are shown in table 2 (samples

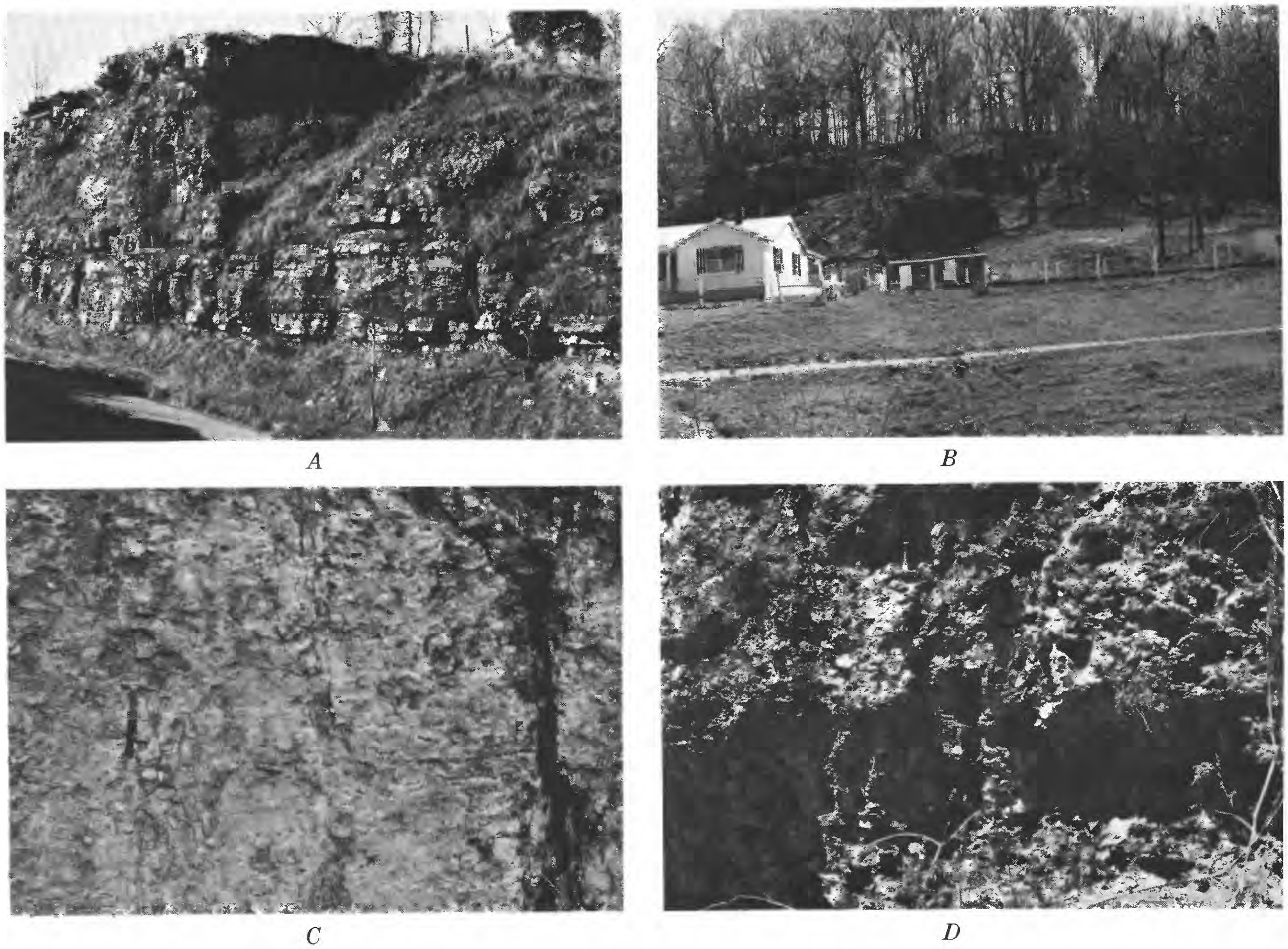


FIGURE 7.—Photographs of the Laurel Dolomite. *A*, Laurel Dolomite, overlying the Osgood Formation; contact at *a*. Reentrant formed by weathering of shale bed at *b*. Beneath is the lowest Laurel subunit, which is 7.5 feet thick. Above the shale bed is the vuggy zone, which is capped at *c* by the basal beds of the quarry stone. Shovel in lower right corner is 3 feet 6 inches long. Roadcut along a county road 150 feet north of the Blue Grass Parkway and 3,200 feet west of the east border of the Cravens quadrangle. *B*, vuggy zone of the Laurel, showing tendency to weather to a single massive ledge and for large blocks to slide away from the outcrop. Bardstown quadrangle, just east of Kentucky Highway 49, ¾ mile north of the Beech Fork. *C*, Vuggy zone of the Laurel in a nearly fresh roadcut showing faint impression of irregular bedding and incipient vug development. Roadcut on north side of the Blue Grass Parkway about ½ mile west of the east border of the Cravens quadrangle. *D*, Vuggy zone of the Laurel showing tendency to weather to a mass of irregular holes surrounded by partitions of dolomite. Bardstown quadrangle, just west of Kentucky Highway 49, ¾ miles north of the Beech Fork.

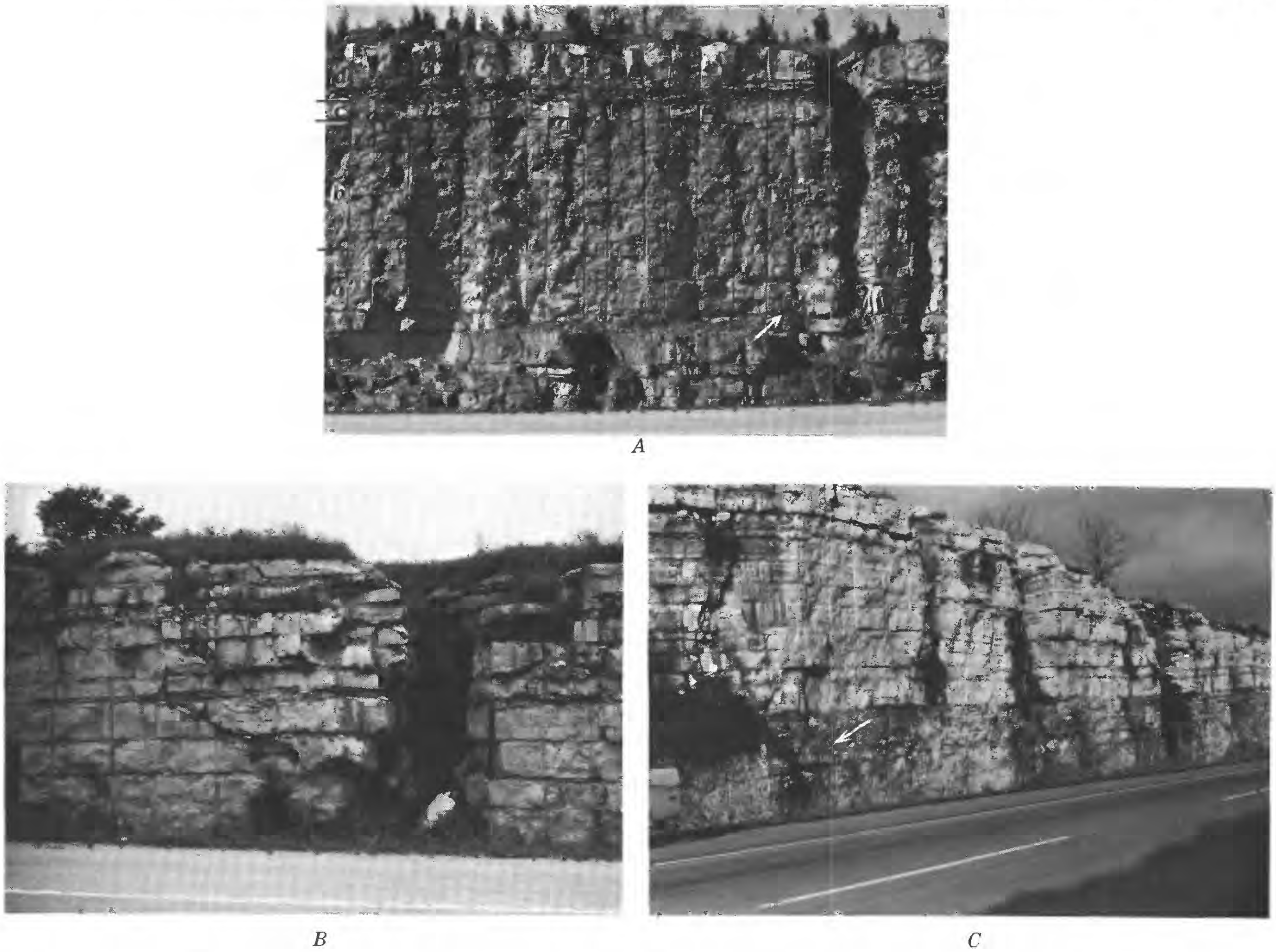


FIGURE 8.—Photographs of the Laurel Dolomite. *A*, Exposure of the Laurel Dolomite and overlying Beechwood Limestone Member of the Sellersburg Limestone showing (*a*) upper part of the quarry stone, (*b*) thin bedded and vuggy weathering zone that overlies the quarry stone, (*c*) dolomitized oolite and calcarenite bed, and (*d*) Beechwood Member of the Sellersburg Limestone. Pre-Beechwood erosion apparently stripped off the Waldron Shale down to the top of the Laurel. Black rod in lower right is 4 feet long. Roadcut on south side of the Blue Grass Parkway ½ mile east of the crossing of U.S. Highway 31E, Bardstown quadrangle. *B*, Exposure of the lower part of the quarry stone. The medium to thick beds are composed of very sparsely fossiliferous, dense, finely crystalline dolomite and are separated by dolomitic shale partings. Middle of the photograph shows a soil-filled solution channel uncovered by highway construction. Black rod is 4 feet long. Roadcut along the north side of the Blue Grass Parkway just west of the east border of the Cravens quadrangle. *C*, Quarry stone overlying the vuggy zone. Black rod (left center) is 4 feet long. Roadcut along the north side of the westbound lanes of U.S. Highway I-71 about 2 miles west of the east border of the Anchorage quadrangle.

L2 and L3). These sections show a mosaic of cloudy anhedral to subhedral carbonate crystals mostly 50 to 100 μm across and abundant larger crystals or aggregates of several crystals as much as several millimeters across (fig. 5*D*). Some of these large crystals are echinoderm ossicles, others are pore fillings. The slides also contain abundant pores ¼ to ½ mm across. The slides contain very sparse grains of pyrite 20 to 40 μm across and abundant opaque grains 10 to 20 μm across that reflect white to reddish-brown light and may be pyrite altered to limonite. One slide cut from the vuggy zone in the Crestwood quadrangle is quite different. It shows a mosaic of clear anhedral to subhedral carbonate crystals measuring mostly 20 to 40 μm across. This slide contains pyrite grains 20 to 40 μm across and abundant unidentified opaque grains 10 μm or less across that may be pyrite or limonite.

Three thin sections were cut from samples of the quarry stone, two from the Cravens quadrangle, and one from the Crestwood quadrangle. Results of analyses of the two samples from the Cravens quadrangle are shown in table 2 (samples L4 and L5). The slides show a mosaic of anhedral to subhedral crystals measuring mostly 30 to 100 μm across and sparse small pores. Pyrite grains, some of which are cubes, are 20 to 80 μm across. The slides contain sparse glauconite grains measuring 100 to 200 μm across and sparse silt-size quartz. They also contain abundant opaque grains about 10 μm across that may be altered pyrite.

One thin section was cut from the dolomitized oolite that caps the formation in part of the outcrop area. The slide shows a mosaic of carbonate crystals, mostly 20 to 50 μm across, which replace the oolites that measure about 1 mm in diameter. The slide also contains a few crinoid columnals. The oolites, whose internal structure is destroyed, are outlined by abundant pores having arcuate boundaries. The slide contains abundant opaque matter, mostly in grains about 10 μm across but also in very irregular and patchy areas as much as 1 mm across. The opaque material reflects white to reddish-brown light and is probably at least in part pyrite altered to limonite.

Results of chemical analyses of the Laurel Dolomite on a foot-by-foot basis of 24 feet at one quarry and 37 feet at another quarry in Jefferson County, Ky., and 15 feet at a quarry in Nelson County, Ky., were given by Stokley and Walker (1953, p. 29, 31, and 47). The chemical analyses included determinations of $CaCO_3$, $MgCO_3$, SiO_2, iron oxide, and alumina.

OUTCROP

The Laurel Dolomite tends to crop out along steep valley sides. The thicker bedded quarry stone subunit crops out as dense smooth rounded ledges. The vuggy zone tends to weather to a single massive bed having an extremely vuggy surface (fig. 7*D*). Large blocks of this subunit separate along joint planes and slide away from the outcrop on the underlying shale (subunit 2). The blocks are found on valley sides in many places (fig. 7*B*).

Sink-hole topography forms on the Laurel where the overlying formations have been stripped away. A large area in the Bardstown quadrangle east of Bardstown is dotted by large shallow sinkholes where the Laurel is immediately below the surface. A solution channel formed in the Laurel quarry stone subunit is shown in figure 8*B*.

WALDRON SHALE

DEFINITION

The Waldron was named by Elrod (1883) for exposures near Waldron, Shelby County, Ind. Usage of the name follows that of Butts (1915) in Jefferson County, Ky. The Waldron extends southward from the area considered here into central Tennessee (Wilson, 1949). According to Berry and Boucot (1970), it correlates eastward with the uppermost part of the Lilley Dolomite of local usage in southern Ohio.

EXTENT AND THICKNESS

The distribution of outcrop of the Waldron Shale and thicknesses recorded on the geologic quadrangle maps are shown on plate 1 (pt. A, 6). The Waldron has a thickness range of 6 to 15 feet; the location of the zero isopach is shown in plate 1, pt. B, 6. The Waldron may be slightly thicker than 15 feet in a small area in the Cravens quadrangle (Peterson, 1968). Across large areas, it is about 10 feet thick.

CONTACTS

The Waldron is underlain by the Laurel Dolomite and is overlain by the Louisville Limestone, except in small areas at the southern end of the main western outcrop belt where it is overlain by the Beechwood Member of the Sellersburg Limestone. The basal contact is generally sharp.

LITHOLOGY

The Waldron Shale is composed of shale and lesser dolomite. The shale is greenish gray or medium gray, contains sparse pyrite, and is generally dolomitic. It weathers to angular fragments or with crude fissility. Advanced weathering produces a yellowish-gray plastic clay. Probably at least 95 percent of the unit is shale. Dolomite is light gray and argillaceous. It is found in irregular masses, lumps, and discontinuous beds (fig. 9*A*). Fossils, which are sparse in the dolomite and shale, include brachiopods, crinoid columnals, gastropods, and bryozoans. A roadcut exposure of the Waldron is shown in figure 10.

OUTCROP

The Waldron is seldom seen in natural exposure. It commonly weathers to gentle slopes and forms a bench on the underlying Laurel.

LOUISVILLE LIMESTONE

DEFINITION

The Louisville was named by Foerste (1897) for exposures at Louisville, Jefferson County, Ky. Usage of the name herein follows that of Butts (1915) in Jefferson County. According to Berry and Boucot (1970), the Louisville correlates with the Lego Lime-

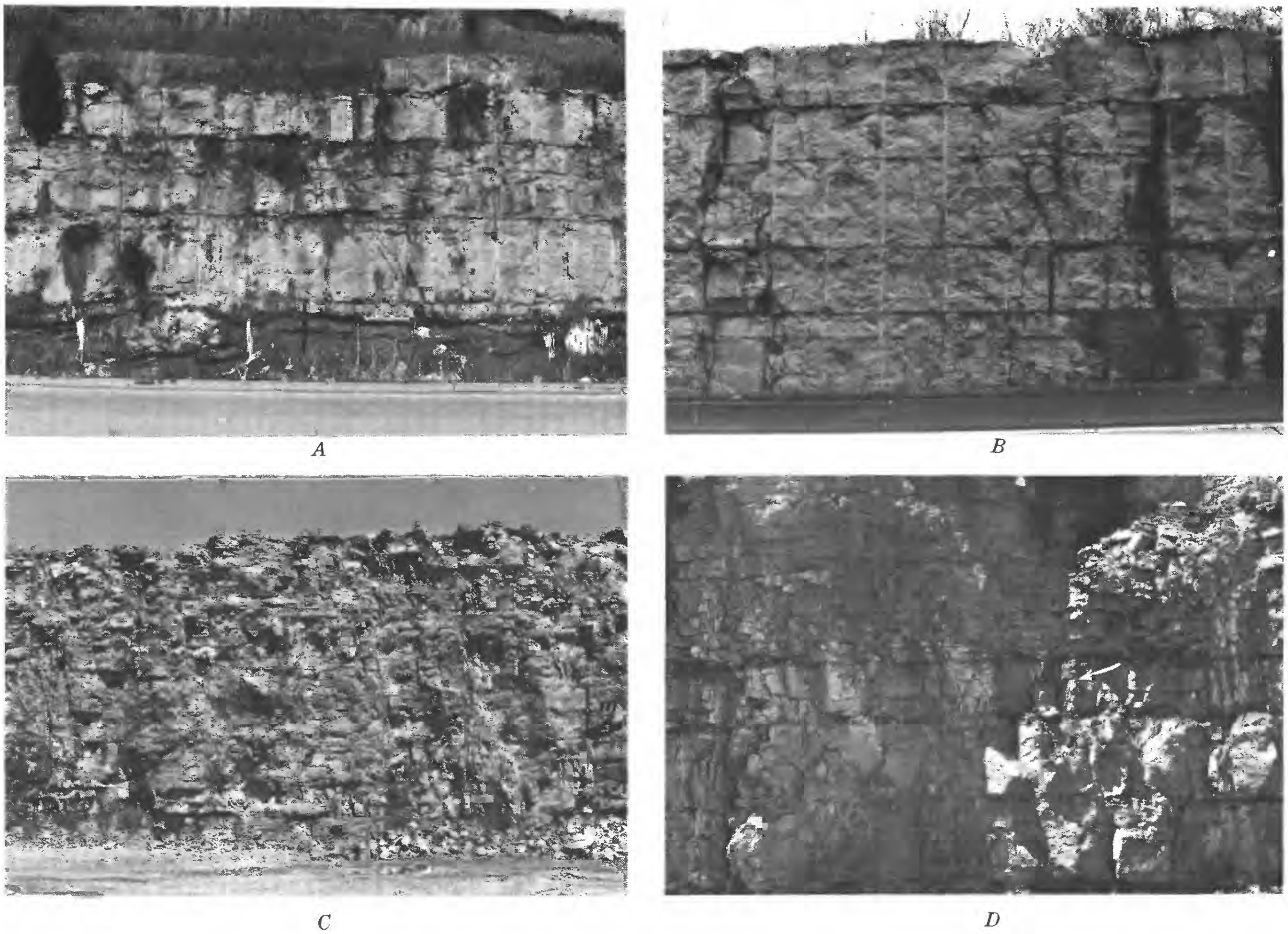


FIGURE 9.—Photographs of the Louisville Limestone. *A*, Louisville Limestone (here a dolomite) overlying the Waldron Shale (contact at *c*), showing tendency for the Louisville to be composed of thick sets of thin beds near base. Note lens of massive dolomite *d* at the top of the Waldron; similar lenses have been found in many places. Roadcut on north side of Blue Grass Parkway at the western edge of the Cravens quadrangle. Black rod is 4 feet long. *B*, Exposure showing thick sets in the middle part of the Louisville in the Jeffersonville quadrangle. Black rod is 4 feet long. Roadcut along River Road near intersection with Blankenbaker Lane. *C*, 60-foot exposure showing tendency of sets in the middle part of the Louisville to be about 2 feet thick. Massive brown-weathering bed *m* is typical of exposures in the southern part of the Brooks quadrangle. Base of the Louisville is reported to be 1 or 2 feet below base of exposure. Black rod is 4 feet long. Bullitt County Stone Co. quarry 0.5 mile south of Bells Mill Road and 0.9 mile east of U.S. Highway I-65, Brooks quadrangle. *D*, Exposure showing tendency of thick sets in the Louisville to divide into thin lumpy beds that are separated by very thin shale seams or stylolites. Exposure is in same quarry as that shown in figure 9*C*.

stone of local usage in western Tennessee and eastward with the Peebles Dolomite of local usage in southern Ohio.

EXTENT AND THICKNESS

The distribution of the Louisville Limestone and thickness ranges recorded on the geologic quadrangle maps are shown on plate 1, pt. A, 7; an isopach map of the unit is shown on plate 1, pt. B, 7. In the main western outcrop belt, the Louisville is thickest in the southern part of the Brooks quadrangle where it reaches about 95 feet. It is thinner to the north and south and has been completely removed by pre-Middle Devonian erosion in the southern part of the main western outcrop belt.

CONTACTS

The Louisville Limestone conformably overlies the Waldron Shale. It is unconformably overlain by Devonian rocks, the Jeffersonville Limestone to the north and the Beechwood Member of the Sellersburg Limestone south of about the middle of the Jeffersontown quadrangle. The basal contact is usually sharp and rarely is gradational through as much as 1 foot.

LITHOLOGY

The Louisville Limestone is mostly dolomitic limestone and calcitic dolomite which intergrade. These rock types are not easily distinguished in the field, and the dominant rock type has not been determined. Both rock types are light gray to light olive gray and weather yellowish gray, light brown, and grayish orange. Most of the Louisville south of the La Grange quadrangle is finely crystalline, is homogeneous, and effervesces weakly in dilute HCl; it is probably calcitic dolomite. It contains clear calcite crystals as much as 1 inch across that are found in irregular aggregates as much as 6 inches or more in largest dimension. Finely crystalline pyrite is present in sparse nodules and irregular aggregates commonly less than 1 inch across. Recognizable fossils are generally sparse and dolomitized and include crinoid columnals, brachiopods, horn corals, and colonial corals. The Louisville is generally composed of thick sets near the base; some sets are 6 feet or more thick (fig. 9*A*). The middle part is either in sets about 2 feet thick, as shown in figure 9*C* or in thicker sets, as shown in figure 9*B*. The upper part contains thin beds 1 to 2 inches thick. The beds are commonly separated by shale partings as much as ¼ inch thick. The sets in the middle and lower part are commonly divided into thin lumpy or irregular beds about 1 inch thick that are separated by very thin seams of shale or by stylolites (fig. 9*D*). These beds are commonly indistinct in the unweathered rock but are distinct on the weathered surface. The thin-bedded upper part of the Louisville is apparently composed largely of these lumpy beds, the thicker sets being indistinct.

North of the southern border of the La Grange quadrangle, most of the Louisville is dolomitic limestone which is light gray to light olive gray and weathers yellowish gray. It is composed of a fine- to coarse-grained matrix containing common to abundant fossil fragments and whole fossils. It forms even sets 1 to 4 feet thick that are composed of ½- to 1-inch-thick distorted and disrupted beds. The sets are separated by shale partings. Fossils include horn corals, colonial corals, stromatoporoids, brachiopods, bryozoans, and crinoid columnals.

Shale constitutes a small part of the Louisville. In addition to forming the partings described above, it is present in very thin beds near the base in the Cravens, Bardstown, and Lebanon Junction quadrangles and locally is present in shale zones about 10 feet thick in the interval from about 15 to 35 feet above the base, as shown on plate 2. The shale is olive gray and dolomitic. Very sparse chert is present in nodules and very thin layers. It is most abundant at the top of the unit in the Jeffersontown and Anchorage quadrangles, as shown on plate 2 (sections 11 and 12).

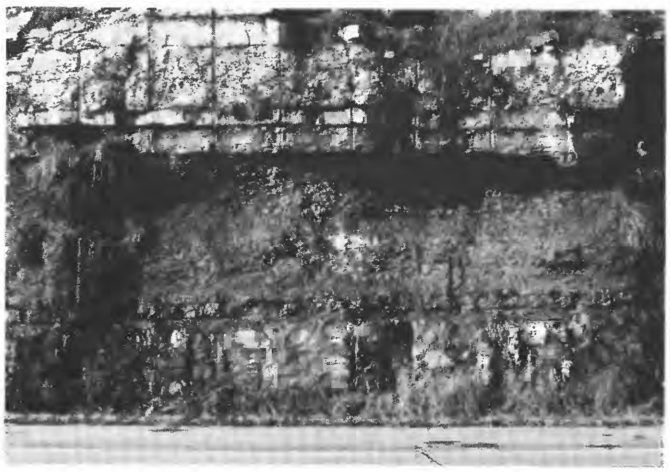


FIGURE 10.—Photograph showing the upper part of the Laurel Dolomite, the Waldron Shale, and the lower part of the Louisville Limestone. Base of the Waldron is at *a* and top is at *b*. At this exposure, the Waldron is mostly dolomitic shale (or mudstone) that weathers to angular fragments. A thin dolomite bed is present in the basal part. Black rod is 4 feet long. Roadcut on north side of U.S. Highway I–71 2.5 miles west of the east border of the Anchorage quadrangle.

PETROGRAPHY

The following description of the Louisville Limestone is based on six thin sections, two each from the Cravens, Jeffersonville, and Anchorage quadrangles. Results of chemical analyses of the two sectioned samples from the Cravens quadrangle (LO1 and LO2) and of another sample from the Cravens quadrangle that was not sectioned (LO3) are given in table 2. Five of the sectioned samples are calcitic dolomites, and one is a dolomitic limestone. Except for fossil fragments and distinct dolomite rhombs, calcite generally could not be distinguished from dolomite in the thin sections.

The five dolomite samples show a mosaic of anhedral to subhedral carbonate crystals measuring mostly from 30 to 100 μm across (fig. 5*F*). These crystals are in part separated by interstitial micrite. In this mosaic are scattered fossil fragments, mostly echinoderm and brachiopod,as long as 1 mm in maximum dimension. Irregular grains of pyrite, 5 to 50 μm across, are scattered through the slides. Silt-size quartz grains are very sparse. The one limestone slide, from the Jeffersonville quadrangle, is composed of fossil fragments, mostly sand size, and interstitial micrite and microspar (fig. 5*E*). Abundant dolomite rhombs are scattered through the slide. Fossils are mostly echinoderm ossicles and brachiopod fragments. Pyrite and quartz are distributed as in the above-described dolomites. Probably the five dolomite samples were originally similar to the limestone, but now most of the calcitic material, excluding a few of the larger fossil fragments and some micrite, has been replaced by dolomite.

Results of chemical analyses on a foot-by-foot basis of 56 feet of the Louisville Limestone were given by Stokely and McFarlan (1952, p. 55–56), and results of analyses of 32 feet in another location were given by Stokley and Walker (1953, p. 25). The two locations are quarries in Jefferson County, Ky. The chemical analyses included determinations of $CaCO_3$, $MgCO_3$, SiO_2, iron oxide, and alumina.

OUTCROP

The Louisville Limestone crops out along steep valley sides. Some beds form persistent ledges that rim steep-walled stream valleys. In some areas where the overlying formations are stripped away, the surface is marked by narrow steep-walled solution cavities and small sinks.

SILURIAN ROCKS IN THE WADDY QUADRANGLE

Silurian rocks in the Waddy quadrangle are nearly horizontal and undisturbed in the middle of the Jeptha Knob cryptoexplosive structure (pl. 1, pt. A). They occupy the highest parts of Jeptha Knob and cover a total area of less than ½ square mile. These rocks unconformably overlie disturbed Clays Ferry Formation of late Middle to early Late Ordovician age. The top of the Clays Ferry is about 375 feet below the base of the Silurian rocks in the normal section a few miles to the west. The basal Silurian unit is 18 feet of limestone and dolomite identified as Brassfield Formation. The overlying rock is not now exposed and the surface is covered with soil and chert residuum to the highest topographic point, which is about 75 feet above the Brassfield. Bucher (1925) and Foerste (1931) concluded, on the basis of thickness and somewhat ambiguous faunal evidence from the chert, that the upper 75 feet include, from the base up, Osgood Formation, Laurel Dolomite, Waldron Shale, and the basal part of the Louisville Limestone. The above discussion was abstracted from Cressman (1975). The reader is referred to that publication and to Cressman (in press) for a more complete discussion.

SILURIAN ROCKS EXPOSED NEAR THE TENNESSEE BORDER

DUBRE AND SULPHUR LICK QUADRANGLES

The Brassfield Dolomite is exposed in the Dubre and Sulphur Lick quadrangles in southern Kentucky (pl. 1, pt. A, 3), but the overlying Silurian formations are missing. The Brassfield unconformably overlies the Cumberland Formation (Upper Ordovician) and is unconformably overlain by the Chattanooga (New Albany) Shale (Upper Devonian). The Brassfield is composed of sparsely fossiliferous reddish- to grayish-brown and brownish-gray, fine- to medium-grained dolomite and contains abundant thin discontinuous lenses and nodules of chert and some interbedded dolomitic siltstone lenses. It ranges in thickness from 0 to 17 feet, being completely cut out in most of the Dubre quadrangle by the unconformity at the base of the Devonian. The above description is abstracted from Lewis (1967). The Brassfield was not identified in the Sulphur Lick quadrangle at the time Harris (1964) mapped it. Subsequently however, it has been shown to be present in a small area in the northeastern part of the quadrangle, in Marrowbone Creek valley just west of the border with the Dubre quadrangle (Richard Q. Lewis, Sr., oral communication, 1978).

PETROLEUM, HOLLAND, FOUNTAIN RUN, AND AUSTIN QUADRANGLES

Silurian rocks crop out just north of the Tennessee border in the Barren River valley and some tributary valleys in the Petroleum, Holland, Fountain Run, and Austin quadrangles (pl. 1, pt. A, 2). All five Silurian formations found in the main outcrop belt probably also are present in the Holland quadrangle. The base of the Silurian rocks is exposed only in the Holland and Fountain Run quadrangles where they unconformably overlie the Cumberland Formation (Upper Ordovician). They are unconformably overlain by Middle Devonian limestone or the Chattanooga (New Albany) Shale (Upper Devonian). The thickness of the Silurian rocks in the area ranges from 0 to 95 feet.

In this area, the Brassfield Dolomite is exposed only in the Holland quadrangle (pl. 1, pt. A, 3), where it is composed of gray or mottled grayish-orange and olive-yellow, fine- to medium-grained dolomite containing beds, lenses, and nodules of chert. It ranges in thickness from 0 to a few feet. Where the base of the Silurian is exposed in the Fountain Run quadrangle, the Brassfield is missing and the Osgood Formation rests directly on the Ordovician.

The Osgood is exposed in the Holland and Fountain Run quadrangles (pl. 1, pt. A, 4), where it is composed of green shale (basal 2 ft locally reddish brown). It ranges in thickness from 0 to 22 feet. The Osgood unconformably overlies the Brassfield where present, and elsewhere unconformably overlies the Cumberland Formation.

The Laurel Dolomite is exposed in the Holland, Fountain Run, Petroleum, and Austin quadrangles (pl. 1, pt. A, 5). It is composed of yellowish-gray, fine- to medium-grained, slightly fossiliferous, thick- to massive-bedded dolomite. The top is preserved only in the Holland quadrangle, where the uppermost bed is an oolitic limestone. The Laurel ranges in thickness from 0 to more than 30 feet in these four quadrangles. The base is gradational.

The Waldron Shale probably is present in the Holland quadrangle (pl. 1, pt. A, 6), where it is composed of yellow-weathering fossiliferous shale. The Louisville Limestone probably also is present in the Holland quadrangle (pl. 1, pt. A, 7), where it is composed of yellowish-gray, fine- to medium-grained, slightly fossiliferous dolomite. The above descriptions of the Silurian units were abstracted from Moore (1961), Nelson (1962), Hamilton (1963), and Myers (1964).

ENVIRONMENTS OF DEPOSITION

The Silurian carbonate rocks west of the Cincinnati arch were originally deposited as marine limestones. They have been subsequently so strongly altered by dolomitization, silicification, and leaching that the original environments of deposition are difficult to determine. Most of the carbonate rocks are fossiliferous, however, and probably were deposited subtidally in normal agitated marine water. The quarry stone subunit of the Laurel appears to have originally been a lime mud and was probably deposited in quiet marine water.

A remarkable feature of the Silurian sedimentary rocks in the main western outcrop belt is the persistence of thin units, as shown on plate 2. These persistent units are recognized mostly from the base of the Osgood upward to the top of the Waldron. The probable explanation for the persistence of minor units must be that the outcrop belt extends along the sedimentary strike and that the isobaths trended nearly north. The slope of the sea bottom is not known, but may have been down to the west because the source of the shales was probably to the east (Freeman, 1951).

TECTONISM OF THE MAIN WESTERN OUTCROP BELT

The thickness variations of the Brassfield and Osgood Formations and of the total Silurian indicate that tectonic movement took place between the time of deposition of the youngest Ordovician rocks and the cutting of the pre-Devonian unconformity.

MOVEMENT DURING BRASSFIELD TIME

South of the Bardstown monocline, the Brassfield Dolomite is thicker than to the north (pl. 2; pl. 1, pt. B, 3). The area of thickening corresponds generally to the position of the monocline. I conclude that this thickening indicates that deeper water existed to the south and that the water depth difference was the result of movement along the Bardstown monocline during or immediately before deposition of the Brassfield. The existence of the minor erosional unconformity at the base of the Brassfield north of the northern part of the Samuels quadrangle and the lack of apparent erosion south of there may also indicate that movement along the monocline raised the Ordovician sedimentary rocks into the zone of erosion, while those to the south remained below. According to Rexroad (1967), the Brassfield is younger to the north than to the south. Movement along the monocline may have caused deeper water to the south where sediments could accumulate in early Brassfield time and shallower water or subaerial exposure to the north where sediments could not accumulate.

The slight thinning of the Brassfield Dolomite south of the northern part of the New Haven quadrangle may indicate that there was less downwarping to the south during Brassfield time than before, and that the syncline so evident on the structure map (pl. 1, pt. B, 1) had its inception in Brassfield time. On the other hand, both the Brassfield and the Osgood cross the Servant Run lineation without changing thickness; thus, that structure must postdate the deposition of the Brassfield and the Osgood.

Thickening of the Brassfield related to tectonic movement may also be recorded in the Crestwood and Ballardsville quadrangles. Figure 11 shows an isopach map of the Brassfield and the structure contours on the base of the Brassfield in these quadrangles. A close correspondence between the lower parts of the Lyndon syncline and the thicker parts of the Brassfield is evident, indicating that the Lyndon syncline originated during or immediately prior to the deposition of the Brassfield sediments. This conclusion was suggested to the writer by Roy

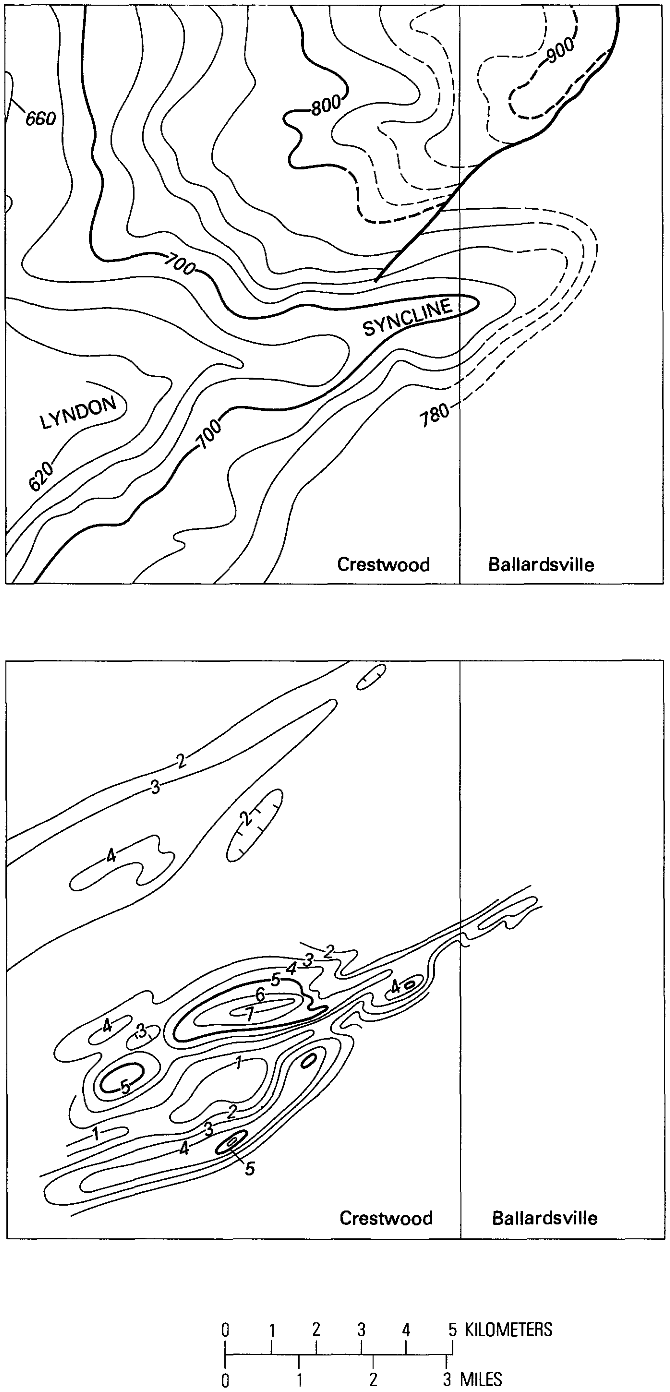


FIGURE 11.—Structure map drawn on the base of the Brassfield Formation (above) and an isopach map of the Brassfield (below) in parts of the Crestwood and Ballardsville quadrangles. Structure contours dashed where projected from a lower horizon. Structure contour interval is 20 feet; isopach interval is 1 foot. The rather close correspondence between the structural trend and the thickness trend suggests that a slight downwarping along the axis of the Lyndon syncline took place during or immediately prior to deposition of the Brassfield. Structure map abstracted from Kepferle (1976, 1977). Isopach map made by Roy C. Kepferle, who also collected the data.

C. Kepferle, who also constructed the isopach map and made the geologic quadrangle maps on which the structure map is based.

MOVEMENT DURING OSGOOD TIME

The Osgood Formation is also thicker south of the Bardstown monocline than it is to the north. The isopach map (pl. 1, pt. B, 4) shows that the Osgood is thickest in the southern part of the Bardstown quadrangle, where it reaches about 50 feet, indicating continued downwarping in this area during Osgood time.

LATER MOVEMENT

A slight thickening of the Laurel Dolomite and possibly the Waldron Shale south of the Bardstown monocline (pl. 2) may indicate slight relative downwarping during deposition of those formations.

Comparison of the isopach map of the total Silurian (pl. 1, pt. B, 2) and the structure contours on the base of the Brassfield (pl. 1, pt. B, 1) indicates that the Silurian sedimentary rocks were warped considerably, prior to the cutting of the pre-Devonian unconformity. An eastward thickening of the Silurian rocks in the Cravens and Bardstown quadrangles corresponds closely to the syncline south of the Bardstown monocline. If the unconformity was smooth and level immediately before the deposition of the Devonian sediments, then considerable downwarping must have taken place before the cutting of the unconformity. All the downwarping shown on the structure map could not have taken place before the formation of the unconformity, however, as the downwarping is greater than the thickness of the preserved Silurian sedimentary rocks. The Silurian sedimentary rocks are also thinner over the top of the east-trending anticline in the northern parts of the St. Catharine, Loretto, and New Haven quadrangles, indicating upwarping before formation of the unconformity. South of this anticline, the relationship between thickness and structure is less clear.

The isopach map (pl. 1, pt. B, 2) shows that the total preserved Silurian rocks thicken generally to the west, indicating that westward downwarping was pronounced prior to the cutting of the pre-Devonian unconformity. This downwarping is also confirmed by the total absence of the Silurian rocks from the crest of the Cincinnati arch on the south flank of the Jessamine dome (fig. 1) before Devonian deposition. Comparison of the structure and the isopach maps indicates that the westward dip has increased greatly since the cutting of the unconformity.

Thickness variations in the Silurian rocks indicate that no general westward warping took place during the deposition of each of the formations. Most of the warping was along lines slightly north or south of west.

SEQUENCE OF TECTONIC MOVEMENT

The following sequence of tectonic movement is suggested by the Silurian rocks:

1. Relative downwarping and Brassfield deposition south of the Bardstown monocline before deposition of the Brassfield, north of the monocline.
2. Downwarping along the Lyndon syncline during Brassfield time.
3. Relative downwarping south of the Bardstown monocline, particularly in the southern part of the Bardstown quadrangle, during Osgood deposition.
4. Possible slight downwarping south of the monocline during deposition of the Laurel and the Waldron.
5. Imposition of a westward dip after deposition of the Silurian sediments.
6. Period of relative quiescence and cutting of a unconformity having small relief.
7. Some minor faulting during deposition of the Beechwood (Boyle) Member of the Sellersburg Limestone and the basal part of the New Albany (Chattanooga) Shale.
8. Many west-trending structural elements are also impressed on the top of the New Albany (Chattanooga) Shale, indicating subsequent folding along west-trending axes. The westerly dip was also greatly increased after the deposition of the New Albany (Chattanooga) Shale.

MEASURED SECTIONS

SECTION 1.—BRASSFIELD DOLOMITE AND OSGOOD FORMATION

[Section measured in the Bardstown quadrangle in roadcuts along the south side of the Blue Grass Parkway just east of the bridge across the Rolling Fork: base of section at 2,081,000 feet E., 525,800 feet N. (Kentucky Coordinate System, south zone). Measured by W. L. Peterson using hand level and tape in April 13, 1978]

	Thickness (feet)
Silurian (incomplete):	
Laurel Dolomite:	
31. Dolomite	(not measured)
Osgood Formation:	
30. Interbedded dolomite (about 50 percent) and clay shale. Dolomite is greenish gray, finely crystalline, and argillaceous. Shale is greenish gray and crudely fissile. Dolomite and shale in even beds 0.2–0.7 foot thick	4.4
29. Dolomite, greenish-gray, finely crystalline, porous; contains sparse pyrite in small crystals; parted into three beds of about equal thickness along most of outcrop	1.7
28. Clay shale, greenish-gray, dolomitic, crudely fissile (in part nonfissile in upper 3 feet); obscurely bedded, beds 0.3 to 0.9 foot thick	11.9
27. Clay shale, greenish-gray, fissile	2.25
26. Clay shale, brownish-gray, fissile	0.8
25. Clay shale, greenish-gray, fissile	0.5
24. Dolomite, argillaceous	0.1
23. Clay shale, greenish-gray and yellowish-brown, crudely interlayered in 0.1- to 0.2-foot-thick layers; crudely fissile; probably dolomitic. Several 0.05-foot-thick argillaceous dolomite layers in upper 1.5 feet	3.2
22. Clay shale, greenish-gray, fissile	3.5
21. Four thin even beds of greenish-gray and grayish-brown argillaceous dolomite and interbedded greenish-gray and grayish-brown dolomitic clay shale; dolomite about 40 percent	1.3
20. Clay shale, about 70 percent grayish-brown and 30 percent greenish-gray, fissile; four 0.1-foot-thick ribs of firm dolomitic shale in unit	3.4
19. Dolomite, brownish-gray, finely crystalline, argillaceous	0.3
18. Clay shale, greenish-gray and brownish-gray, fissile	1.0
17. Dolomite, greenish-gray, finely crystalline, argillaceous	0.25
16. Clay shale, greenish-gray, fissile	0.25
15. Dolomite, greenish-gray, finely crystalline, argillaceous	0.25
14. Clay shale, greenish-gray and brownish-gray, fissile	1.25
Total thickness of Osgood Formation	36.4
Brassfield Dolomite:	
13. Dolomite, light-greenish-gray, weathers grayish orange; finely crystalline, porous; contains molds of tiny crinoid columnals; in irregular beds 0.05 to 0.1 foot thick	0.9
12. Dolomite, similar to unit 10; beds 0.1 to 0.4 foot thick	0.9
11. Clay shale, light-greenish-gray	0.9
10. Dolomite, light-olive-gray, light-greenish-gray, and yellowish-gray; fine to medium crystalline; in generally even beds having somewhat lumpy tops and bases; beds are 0.1 to 0.8 foot thick and, in part, are divided into faint lumpy layers about 0.1 foot thick; beds separated in part by stylolites. Dolomite is porous, slightly glauconitic, and contains sparse nodules of chert, sparse irregular clots of clear calcite, and sparse nodules of fine crystalline pyrite	5.2

	Thickness (feet)
Brassfield Dolomite—Continued:	
9. Dolomite, light-gray to medium-gray, fine- to medium-crystalline; contains sparse irregular clots of clear calcite; in faint even beds several tenths of a foot thick that are in part faintly divided into thin lumpy beds like those in unit below; beds in part separated by stylolites. Base of unit is a conspicuous stylolite	3.25
8. Dolomite, light-olive-gray, mottled yellowish gray; fine to medium crystalline, sparsely glauconitic, in very contorted, disrupted, and discontinuous beds 0.05 to 0.1 foot thick that are separated by discontinuous and contorted partings of dark-olive-gray (argillaceous?) finely crystalline dolomite about 0.01 foot thick. The dark partings are recessed and are apparently less resistant to weathering than lighter colored dolomite. Unit contains many conspicuous stylolites. Dolomite contains irregular clots of very coarsely crystalline clear calcite, which are several tenths of a foot in long dimension; they contain crystals of pyrite, some octahedral, as much as 0.03 foot in long dimension; brown sphalerite crystals are present along the edges of some calcite clots. Dolomite also contains nodules and lenses of light-gray fossiliferous and glauconitic chert along bedding planes	8.0
7. Dolomite, olive-gray, fine- to medium-crystalline, porous, glauconitic; in obscure contorted beds 0.05 to 0.1 foot thick. Similar to unit 8, but is darker	2.2
6. Dolomite, olive-gray, fine- to medium-crystalline, porous, sparsely glauconitic; in very irregular laminae 0.02 to 0.05 foot thick; common ghosts of crinoid columnals; forms single massive bed	4.0
Total thickness of Brassfield Dolomite	25.4
Ordovician (incomplete):	
Saluda Dolomite Member of Drakes Formation:	
5. Clay shale, olive-gray, dolomitic, weakly fissile	0.1–0.25
4. Dolomite, olive-gray, finely crystalline	0.1
3. Dolomite, olive-gray, finely crystalline; in slightly wavy laminae about 0.01 foot thick	0.3–0.4
2. Shale	0.02
1. Dolomite, grayish-green, finely crystalline, covered below	12.0
Incomplete thickness of the Saluda Dolomite Member	12.6

SECTION 2.—LAUREL DOLOMITE AND WALDRON SHALE

[Lower part of section, up to top of unit 11 (top of the vuggy zone of the Laurel), measured in roadcuts along county road 150 feet north of the Blue Grass Parkway and 3,200 feet west of the east border of the Cravens quadrangle; upper part of section (above vuggy zone) measured in roadcuts along the north side of the Blue Grass Parkway 2,200 feet west of the east border of the Cravens quadrangle; base of section at 2,069,200 feet E., 527,000 feet N. (Kentucky Coordinate System, south zone). Measured by W. L. Peterson using hand level and tape on April 14, 1978]

	Thickness (feet)
Silurian (incomplete):	
Louisville Limestone:	
19. Dolomite, very irregular base, covered above	1.0
Waldron Shale:	
18. Clay shale, dark-greenish-gray, dolomitic; breaks into angular fragments; contains small pyrite cubes in parts. Greenish-gray to olive-gray and finely crystalline dolomite is present in lenses several feet long and as thick as 1.5 feet; one lens just above base and two in the upper 4 feet. Basal contact sharp	10.5
Total thickness of Waldron Shale	10.5
Laurel Dolomite:	
17. Dolomite, oolite, grayish-orange to light-brown (weathered), fine- to medium-crystalline, porous, laminated and crossbedded; contains abundant dolomitized brachiopods and crinoid columnals	1.5
16. Dolomite, olive-gray, weathering grayish orange and light brown, porous and laminated; dolomitized well-sorted fossil "hash"	3.7
15. Dolomite, olive-gray, finely crystalline and porous containing abundant patches of medium crystalline, coarser textured, more porous dolomite that is yellowish gray to grayish orange. Both types of dolomite contain abundant molds of tiny crinoid columnals. Unit faintly bedded into irregular beds 0.1 to 0.2 foot thick. Weathered surface of unit is vuggy	6.8
14. Dolomite, similar to unit 13, except that most beds are 0.5 to 0.7 foot thick; some dolomitized fossils, including trilobites and crinoid columnals. Top of this unit is top of quarry stone referred to elsewhere in report	3.2
13. Dolomite, similar to unit 12, except beds faintly layered into thin irregular beds 0.05 to 0.1 foot thick. These thin beds separated by 0.01-foot-thick (argillaceous?) dolomite partings	5.0
12. Dolomite, light-gray, weathers yellowish gray, very finely crystalline, slightly porous, contains sparse	

	Thickness (feet)
Laurel Dolomite—Continued:	
glauconite, sparse aggregates of fine-crystalline pyrite, sparse aggregates of very coarsely crystalline clear calcite and sparse to common molds of tiny crinoid columnals. Stratified into even beds 0.9 foot to 1.9 feet thick that have slightly wavy tops and bases and are separated by shale partings and 0.1- to 0.2-foot-thick beds of dolomite. Dolomite has a fine-grained even texture on the freshly broken surface. The beds are virtually structureless internally. Base of unit is sharp even contact. Base of this unit is base of quarry stone referred to elsewhere in report	12.6
11. Dolomite, heterogeneous mixture of olive-gray, finely crystalline, slightly porous dolomite and grayish-orange, iron-stained, fine- to medium-crystalline, very porous, dolomite containing abundant iron-oxide-lined molds of tiny crinoid columnals and fragments of other fossils. Unit contains abundant calcite-lined vugs 0.02 to 0.2 foot long and 0.01 to 0.05 foot deep and abundant dolomitized crinoid columnals and brachiopods. Unit is single massive stratum faintly layered into irregular disrupted beds 0.05 to 0.2 foot thick. Base of unit is uneven. This unit is the vuggy zone referred to elsewhere in this report	19.5
10. Clay shale, olive-gray, and dolomite; thinly interlayered	0.5–1.0
9. Dolomite, similar to unit 8 but in somewhat uneven beds 0.2 to 0.7 foot thick	2.3
8. Dolomite, pale-olive to grayish-orange (weathered and iron-stained), fine- to medium-crystalline, very porous; contains abundant molds of crinoid columnals and other fossil fragments; in faint irregular and disrupted beds 0.05 to 0.1 foot thick	3.25
7. Shale, light-olive-gray, dolomitic	0.02
6. Dolomite, light-gray, weathers pale-olive and grayish-orange, very finely crystalline, porous; abundant molds of crinoid columnals, sparse pyrite; in even indistinct beds 0.1 to 0.4 foot thick	2.9
Total thickness of Laurel Dolomite	61.5
Osgood Formation:	
5. Clay shale, similar to unit 1	1.75
4. Dolomite, similar to unit 2	0.25
3. Dolomite, similar to unit 2 but more argillaceous and less resistant	0.6
Osgood Formation—Continued:	
2. Dolomite, greenish-yellow, mottled grayish-orange (weathered), finely crystalline, argillaceous; forms ledge	0.75
1. Clay shale, greenish-gray, weathers pale-olive and yellowish-gray, dolomitic; covered below	4.5
Incomplete thickness of Osgood Formation	7.9

SECTION 3.—LOUISVILLE LIMESTONE

[Partial section of the Louisville Limestone measured in an inactive quarry in the Brooks quadrangle (Bullitt County, Ky.) ¼ mile east of U.S. Highway I-65 and ¾ mile south of Hebron Lane; base of section at 200,500 feet E., 1,584,000 feet N. (Kentucky Coordinate System, north zone). Measured by Roy C. Kepferle using hand level and tape on September 23, 1966]

	Thickness (feet)
Louisville Limestone (upper part not exposed):	
8. Dolomite, thin-bedded, rubbly, to top of quarry	7.0
7. Dolomite, light-olive-gray to yellowish-gray, very finely crystalline (sucrosic); massive weathering, has rubbly surface; fossil casts abundant; some calcite; discontinuous chert at base and 1.9 and 2.5 feet above base	12.0
6. Dolomite, light-olive-gray; very finely crystalline, containing denser, medium-gray fossil fragments; calcite scattered throughout; pyritic; ledges 0.1 to 1.5 feet thick. *Halysites* (chain coral) below top. Basal more massive layer weathers medium light gray to light olive gray	19.0
5. Dolomite, similar to underlying unit, but contains some limestone blebs; weathers to single massive bench; *Halysites* in top 1 foot; horn corals, bryozoans, brachiopods visible on weathered surface	3.5
4. Dolomite, yellowish-gray; calcitic; beds 0.4 foot thick	2.0
3. Limestone, yellowish-gray, variegated or mottled light-olive-gray where dolomitic; pyritic; chert in a scattered blebs	5.0
2. Dolomite, calcareous, light-olive-gray to greenish-gray; calcitic concentrations	1.3
1. Limestone, yellowish-gray; dolomitic part is light-olive-gray and imparts a mottled appearance to the rock. Limestone is very finely crystalline. Chert is white to light-gray in discontinuous layers as much as 0.2 foot thick at 1.8 and 4.0 feet above base and 0.8 foot below top of unit. Beds marked by stylolites 0.5 to 1.0 foot apart	9.2
Covered by water	----
Total exposed Louisville Limestone	59.0

LIST OF SECTIONS OF SILURIAN ROCKS THAT WERE WELL EXPOSED IN 1978

RAYWICK QUADRANGLE

Brassfield: Roadcut along county road leading south from Raywick, Ky., at southern edge of town.

BARDSTOWN QUADRANGLE

1. Saluda Dolomite Member of the Drakes Formation upward to near top of Laurel quarry stone; best exposure of the entire Osgood Formation in the area in 1978: Several roadcuts along the Blue Grass Parkway extending east for about 1 mile from the Beech Fork.
2. Upper three-fourths of the Osgood Formation, showing rib of dolomite that is present in the upper part of the formation in this area: Artificial exposures at power station and behind stores in Bardstown, about 1/5 mile north of the intersection of U.S. Highways 62 and 150.
3. Upper 20 feet of Osgood Formation and lower 5 feet of Laurel Dolomite, showing rib of dolomite that is present in the upper part of the Osgood in this area: Roadcuts along U.S. Highway 150 just east and west of Rowan Creek.
4. Exposures of upper part of Saluda, Brassfield, and virtually entire Osgood: Roadcuts along U.S. Highway 150 east and west of Mill Creek.
5. Upper part of Saluda upward to upper part of Laurel quarry stone; Osgood poorly exposed: Roadcuts along U.S. Highway 31E north and south of the Beech Fork.
6. Laurel vuggy zone upward to oolite at top; immediately overlain by the Beechwood Member of the Sellersburg Limestone; same outcrop shown on figure 8*A*: Roadcuts along Blue Grass Parkway 1/2 mile east of U.S. Highway 31E.

CRAVENS QUADRANGLE

1. Saluda Dolomite Member of the Drakes Formation upward into the lower part of the Laurel quarry stone; Osgood partly exposed: Roadcuts along U.S. Highway 62 east and west of Buffalo Creek (at the Bardstown Reservoir).
2. Lower part of Laurel upward to basal part of Louisville Limestone; good exposure of Waldron Shale: Roadcuts along the Blue Grass Parkway 1/4 mile west of the east border of the quadrangle.
3. Upper part of Saluda upward to the upper part of the Laurel quarry stone; Osgood partly exposed; includes outcrop shown in figure 4*A*: Roadcuts along the Blue Grass Parkway east and west of the Beech Fork.
4. Upper few feet of Laurel, Waldron, and lower 20 feet of Louisville; Waldron well exposed: Roadcuts along the Blue Grass Parkway just east of the western boundary of the quadrangle.
5. Good exposure of the lower dolomite, the shale bed, the vuggy zone, and quarry stone of the Laurel Dolomite; same outcrop as shown in figure 7*A* : Roadcuts along the county road just north of the Blue Grass Parkway, 0.6 mile west of the east border of the quadrangle.
6. Upper part of Laurel, Waldron, lower few feet of Louisville, Beechwood, and lower part of New Albany Shale; good exposure of Waldron and Laurel oolite: Inactive quarry just north of the Blue Grass Parkway, 0.7 mile west of Snake Run.

SAMUELS QUADRANGLE

Brassfield: Roadcut along Kentucky Highway 480 about 1.5 miles west of Cox Creek, near Solitude, Ky.

SHEPHERDSVILLE QUADRANGLE

Upper 20 feet of Laurel, Waldron (partly exposed), and lower 30 feet of Louisville: Several roadcuts along Kentucky Highway 245 from Clermont, Ky., eastward to just beyond the eastern border of the quadrangle.

MT. WASHINGTON QUADRANGLE

Brassfield and lower part of Osgood dolomite well exposed; rest of Osgood poorly exposed: Roadcut along U.S. Highway 31E, 1 mile north of central part of Mt. Washington, Ky.

BROOKS QUADRANGLE

1. Louisville Limestone; about 60 feet exposed; top and base covered: Bullitt County Stone Company quarry, 1/2 mile south of Bells Mill road and 1 mile east of U.S. Highway I–65.
2. Louisville Limestone; about 75 feet exposed; top and base covered: Quality Crushed Stone Company quarry, 5/8 mile south of Bells Mill road and 3/4 mile east of U.S. Highway I–65.
3. Louisville Limestone; about 59 feet exposed; top and base covered; same exposure as measured section 3 (p. C26); difficult access in 1978: Abandoned quarry 3/4 mile south of Hebron Lane, 1/4 mile east of U.S. Highway I–65.

JEFFERSONTOWN QUADRANGLE

1. Brassfield: Roadcuts at intersection of Kentucky Highways 841 (Jefferson Freeway) and 155.

2. Brassfield (not well exposed), Osgood, and lower 8 feet of Laurel: Roadcuts at intersection of U.S. Highway I–64 and Kentucky Highway 841 (Jefferson Freeway).

JEFFERSONVILLE QUADRANGLE

Upper part of Laurel, Waldron, and lower part of Louisville: Roadcuts along U.S. Highway 42 between 0 and 1 mile north of U.S. Highway I–71.

ANCHORAGE QUADRANGLE

Jeffersonville Limestone of Devonian age overlying about 20 feet of Louisville Limestone; contact is planar: Roadcut at intersection of U.S. Highway 42 and Kentucky Highway 841 (Jefferson Freeway).

ANCHORAGE AND CRESTWOOD QUADRANGLES

Excellent exposures of the upper few feet of the Saluda upward through the lower 20 feet of the Louisville Limestone: Many roadcuts along U.S. Highway I–71 from the Oldham County-Jefferson County line in the Anchorage quadrangle eastward to just east of Kentucky Highway 329 in the Crestwood quadrangle and in roadcuts along Kentucky Highway 329 north and south of U.S. Highway I–71.

OWEN QUADRANGLE

Enigmatic severe faulting and folding of Brassfield, Osgood, and lower part of Laurel, which was briefly described by Gauri and others (1969): Roadcuts along Kentucky Highway 1793 just east of Island Road.

LA GRANGE QUADRANGLE

Brassfield, Osgood, and lower part of Laurel; Osgood well exposed: Roadcuts along Kentucky Highway 53, ½ mile south of Harrods Creek.

REFERENCES CITED

Berry, W. B. N., and Boucot, A. J., eds., 1970, Correlation of the North American Silurian rocks: Geological Society of America Special Paper 102, 289 p.

Browne, Ruth, Conkin, J. E., Conkin, Barbara, and MacCary, L. M., 1958, Sedimentation and stratigraphy of Silurian and Devonian rocks in the Louisville area, Kentucky—Geological Society of Kentucky, field trip itinerary, May 1958: Lexington, Ky., 46 p.

Bucher, W. H., 1925, Geology of Jeptha Knob: Kentucky Geological Survey, Series 6, [Geologic Reports], v. 21, p. 193–237.

Butts, Charles, 1915, Geology and mineral resources of Jefferson County, Kentucky: Kentucky Geological Survey, Series 4, [Reports], v. 3, pt. 2, 270 p.

Cressman, E. R., 1975, Geologic map of the Waddy quadrangle, central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–1255, scale 1:24,000.

——— in press, Surface geology of the Jeptha Knob cryptoexplosion structure, Shelby County, Kentucky: U.S. Geological Survey Professional Paper 1151–B.

Elrod, M. N., 1883, Geology of Decatur County, Indiana: Indiana Department of Geology and Natural History Annual Report 12, p. 100–152.

Foerste, A. F., 1896, An account of the Middle Silurian rocks of Ohio and Indiana: Cincinnati Society of Natural History Journal, v. 18, nos. 3 and 4, p. 161–199.

——— 1897, A report on the geology of the Middle and Upper Silurian rocks of Clark, Jefferson, Ripley, Jennings, and southern Decatur Counties: Indiana Department of Geology and Natural Resources Annual Report 21, p. 213–288.

——— 1905, Silurian clays, with notes on clays of the Waverly and Irvine Formations [of Kentucky]: Kentucky Geological Survey Bulletin 6, p. 143–178.

——— 1906, The Silurian, Devonian, and Irvine Formations of east-central Kentucky, with an account of their clays and limestones: Kentucky Geological Survey Bulletin 7, 369 p.

——— 1931, Silurian fauna, *in* Jillson, W. R., ed., The paleontology of Kentucky: Kentucky Geological Survey, Series 6, v. 36, p. 167–212.

——— 1935, Correlation of Silurian formations in southwestern Ohio, southeastern Indiana, Kentucky, and western Tennessee: Denison University Bulletin, v. 35, no. 14, p. 119–205.

Freeman, L. B., 1951, Regional aspects of Silurian and Devonian stratigraphy in Kentucky: Kentucky Geological Survey, Series 9, Bulletin 6, 565 p., (reprinted 1959).

French, R. R., 1967, Crushed stone resources of the Devonian and Silurian carbonate rocks of Indiana: Indiana Geological Survey Bulletin 37, 127 p.

Gauri, K. L., Noland, A. V., and Moore, Bruce, 1969, Structurally deformed Late Ordovician to Early Silurian strata in north-central Kentucky and southeastern Indiana: Geological Society of America Bulletin, v. 80, no. 9, p. 1881–1886.

Guerrero, R. G., and Kenner, C. T., 1955, Classification of Permian rocks of western Texas by a versenate method of chemical analysis: Journal of Sedimentary Petrology, v. 25, no. 1, p. 45–50.

Hamilton, Warren, 1963, Geology of the Fountain Run quadrangle, Kentucky-Tennessee: U.S. Geological Survey Geologic Quadrangle Map GQ–254, scale 1:24,000.

Harris, L. D., 1964, Geology of the Sulphur Lick quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–323, scale 1:24,000.

Kentucky Geological Survey, 1954, Geologic map of Kentucky: Lexington, Ky., Kentucky Geological Survey, Series 9, scale 1:1,000,000.

Kepferle, R. C., 1969, Geologic map of the Samuels quadrangle, north-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–824, scale 1:24,000.

——— 1973, Geologic map of the Raywick quadrangle, central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–1048, scale 1:24,000.

——— 1976, Geologic map of the Crestwood quadrangle, north-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–1342, scale 1:24,000.

——— 1977, Geologic map of the Ballardsville quadrangle, north-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–1389, scale 1:24,000.

Kepferle, R. C., Wigley, P. B., and Hawke, B. R., 1971, Geologic map of the Anchorage quadrangle, Jefferson and Oldham Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-906, scale 1:24,000.

Lewis, R. Q., Sr., 1967, Geologic map of the Dubre quadrangle, southern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-676, scale 1:24,000.

McDowell, R. C., Grabowski, G. J., Jr., and Moore, S. L., in press, Geologic map of Kentucky: Reston, Va., U.S. Geological Survey, 3 sheets, scale 1:250,000.

McFarlan, A. C., 1943, Geology of Kentucky: Lexington, Ky., University of Kentucky Press, 531 p.

Moore, S. L., 1961, Geology of the Austin quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-173, scale 1:24,000.

——— 1978, Geologic map of the Parksville quadrangle, Boyle and Casey Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1494, scale 1:24,000.

Myers, W. B., 1964, Geology of the Petroleum quadrangle, Kentucky-Tennessee: U.S. Geological Survey Geologic Quadrangle Map GQ-352, scale 1:24,000.

Nelson, W. H., 1962, Geology of the Holland quadrangle, Kentucky-Tennessee: U.S. Geological Survey Geologic Quadrangle Map GQ-174, scale 1:24,000.

Nicoll, R. S., and Rexroad, C. B., 1968, Stratigraphy and conodont paleontology of the Salamonie Dolomite and Lee Creek Member of the Brassfield Limestone (Silurian) in southeastern Indiana and adjacent Kentucky: Indiana Geological Survey Bulletin 40, 73 p.

Nosow, Edmund, 1959, Stratigraphy of Nelson County and adjacent areas—Geological Society of Kentucky field trip, May 8-9, 1959: Lexington, Ky., Kentucky Geological Survey, 37 p.

O'Donnell, Edward, 1967, The lithostratigraphy of the Brassfield Formation (Lower Silurian) in the Cincinnati Arch area: Cincinnati, Ohio, University of Cincinnati, Ph.D. thesis, 205 p.

Peterson, W. L., 1968, Geologic map of the Cravens quadrangle, Bullitt and Nelson Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-737, scale 1:24,000.

——— 1969, Geologic map of the Bardstown quadrangle, Nelson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-825, scale 1:24,000.

Rexroad, C. B., 1967, Stratigraphy and conodont paleontology of the Brassfield (Silurian) in the Cincinnati Arch area: Indiana Geological Survey Bulletin 36, 64 p.

Stokley, J. A., and McFarlan, A. C., 1952, Industrial limestones of Kentucky No. 2: Kentucky Geological Survey, Series 9, Report of Investigations 4, 95 p.

Stokley, J. A., and Walker, F. H., 1953, Industrial limestones of Kentucky No. 3: Kentucky Geological Survey, Series 9, Report of Investigations 8, 62 p.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, no. 5, p. 377-392.

Wilson, C. W., Jr., 1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Division of Geology Bulletin 56, 407 p.

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