GUIDEBOOK NO. 13

SAMPLING THE LAYER CAKE THAT ISN'T: THE STRATIGRAPHY AND PALEONTOLOGY OF THE TYPE-CINCINNATIAN

Richard Arnold Davis and Roger J. Cuffey, Editors

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17. PALEOGEOGRAPHY AND PALEOENVIRONMENTS, FAIRVIEW THROUGH WHITEWATER FORMATIONS (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA AND SOUTHWESTERN OHIO)

by
Helen B. Hay

INTRODUCTION

The focus of this paper is the lithofacies of about 122-168 meters (400-550 ft) of section that includes the upper part of the Kope Formation through the Whitewater Formation to the Ordovician/Silurian contact in southeastern Indiana and southwestern Ohio. The goal is to determine what the stratigraphic and geographic distribution of the facies suggests about the paleogeography, paleoenvironments, and geologic history of the area. The rocks are thin gray limestones composed of whole and broken marine fossils interbedded with compacted, but not cemented, terrigenous clay and silt that are traditionally called shales, although they are more accurately classified as mudstones. Facies intervals differ from each other in the proportion of shale to limestone and in internal and bedding characteristics of both rock types.

Gray (1972) assigned the Upper Ordovician of Indiana to the Maquoketa Group and identified four provinces: a deep basin in the southwest, a western shelf in the northwest, an eastern shelf, and a southeastern shelf. Most of the limestones are in the eastern part of the eastern shelf and in the southeastern shelf, the eastern parts of which include the area of this study. Most of the Cincinnatian of the central and western parts of the state is shale. Weir and Peck (1968) and Cressman (1973) studied the Middle and Upper Ordovician rocks of Kentucky, most of which are shallow-water limestones. So this paper deals with details of an area viewed as shelf from central Indiana and basin from central Kentucky.

In general, these sediments accumulated on a shallow marine shelf at depths that ranged from above normal wave base to, more commonly, near or below storm wave base. The large number of thin facies intervals suggests that the depositional environment was subject to frequent minor changes that would be expected in very shallow seas rather than in the more stable environments of deeper shelves. The regional facies patterns show wedges of >70 percent shale that thicken toward the northwest or northeast. These shale wedges intertongue with limestone-rich zones of <70 percent shale that thicken first toward the south then, later in the Cincinnatian, along a more nearly north-south axis. Most of the contacts between units are gradational and, therefore, are believed to be time transgressive. The characteristics of the lithofacies, as well as their stratigraphic relationships based on isopach maps, leads to a reasonable interpretation of depositional environments, paleogeography, and transgressive/regressive cycles.

Localities included in the study are shown in figure 17-1 and are listed at the end of this paper. Hay (1981) described the geographically named localities, five of which are cores: New Point, Wayne County, Randolph County, Miamisburg, and Middletown. Descriptions of part of the Brookville composite section and of some other localities were published by Hay and others (1981), and a portion of the Madison composite section by Totten and Hay (1987). The numbered localities (1-22) are mostly from Kentucky GQ maps. Information from open-file core descriptions provided by the Ohio Division of Geological Survey (2627 in Warren County; 2537, 2981, 2982, and 2984 in Butler County; and 3023 in Preble County) are incorporated, to the extent possible, in this discussion. Several localities are described in other papers in this volume: the Indiana Route 1 road cut at South Gate Hill (IN-FR-0005; paper 12 in this volume); the Madison, Indiana, road cuts (IN-JE-0001, IN-JE-0002, and IN-JE-0003; paper 6); the Brookville Dam spillway (IN-FR-0002; paper 8); Bon Well Hill (IN-FR-0001; paper 10); Garr Hill/Brookville North (IN-FR-0003; paper 11); and the U.S. Route 27 road cut near Richmond, Indiana (IN-WY-0001; paper 15).

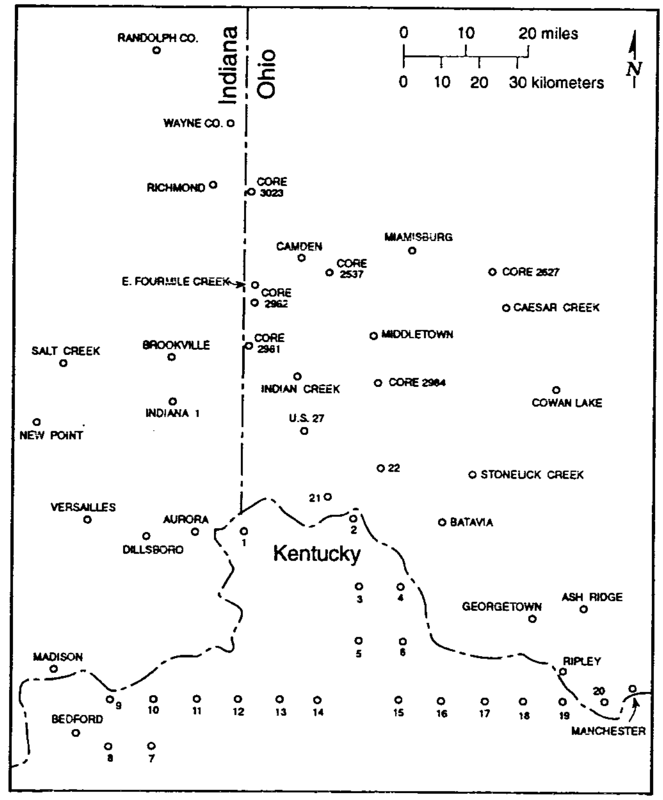

FIGURE 17-1.—Index map (modified from Hay, 1981). Localities marked "core" are cores of the Ohio Division of Geological Survey. For references for numbered localities (1-22) see Localities on p. 132-133.

LITHOFACIES AND STRATIGRAPHY

LITHOFACIES CLASSIFICATION

The lithofacies classification that underpins this discussion was developed through detailed study of the Brookville and Richmond composite sections (Hay, 1975), then modified and applied regionally (Hay, 1981). It is a field classification that has proven effective in describing both outcrops and cores. The key characteristics of the lithofacies are summarized in figure 17-2. There are four facies groups. Groups 1, 2, and 3 are distinguished on the basis of the shale percentage in an interval: >70 percent, 55-70 percent, and <55

Group	Facies	Principal diagnostic characteristics of lithofacies
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

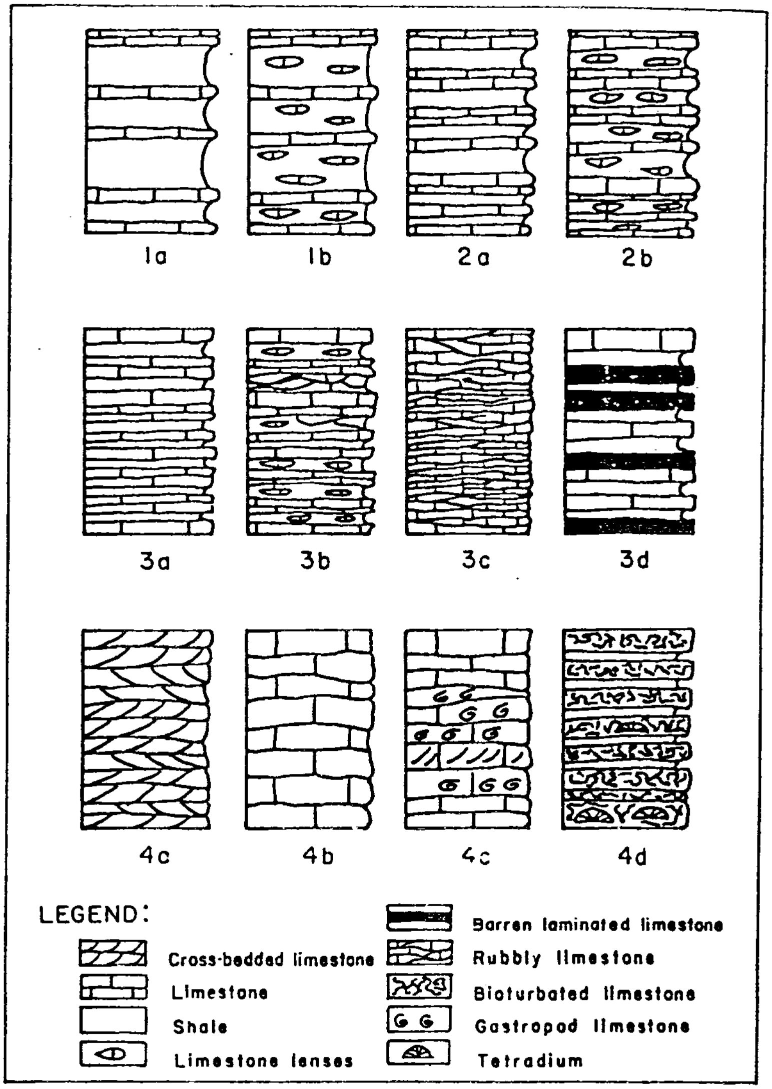

FIGURE 17-2.—Principal diagnostic characteristics of lithofacies and illustration of lithofacies types. Modified from Hay (1981) and Hay and others (1981).

percent, respectively. Within these three groups the letter designations are based on the nature of the shales and limestones. The letter "a" indicates a predominance of planar rather than nodular or rubbly limestones and shales that are predominantly free of calcareous stringers, lenses, or nodules. The "b" facies have calcareous stringers, lenses, or nodules in the majority of the shales. Group 3 (<55 percent shale) has two additional facies: 3c, containing nodular, rubbly limestones and limy shales, and 3d, containing planar limestones, >20 percent of which are laminated, burrowed, and composed of silt- and fine-sand-sized allochems. The latter facies appears to be unfossiliferous in hand specimen or outcrop. The facies of group 4 are much less common but are useful environmental indicators where they occur. The classification is open ended in that all four groups can be expanded, if the need arises.

FORMATIONS AND MEMBERS

Regional correlation of lithofacies (Hay, 1981, pls. 1 and 2) suggests a reasonable division of the Cincinnatian Series into formations and members (Hay 1981, pl. 3) that is somewhat different from that currently in use in Indiana and Ohio (fig. 17-3). The Indiana Geological Survey recognizes four formations: the Kope, Dillsboro, Saluda, and Whitewater Formations. The Ohio Division of Geological Survey recognizes the Kope and Fairview Formations, Miamitown Shale, Grant Lake Formation (divided into the Bellevue, Corryville, and Mt. Auburn Members by Schumacher, Swinford, and Shrake, 1991), the Arnheim formation (informal), the Waynesville, Liberty, and Whitewater Formations, and the Elkhorn shale (informal). In south-central Ohio, the Ohio Survey recognizes the Drakes Formation at the top of the Ordovician.

My suggestion, presented here informally, incorporates some of the units of Ohio and Indiana, but, in some respects, is different from either. It is illustrated schematically along a south-north cross section in figure 17-4. The Kope (facies 1a), Fairview (facies 2a and 3a), Miamitown (facies 1a), and Bellevue (facies 3b and 3c) can be traced throughout the area and should be retained in Ohio and recognized in Indiana.

The Bellevue lithology is similar to that of the Whitewater

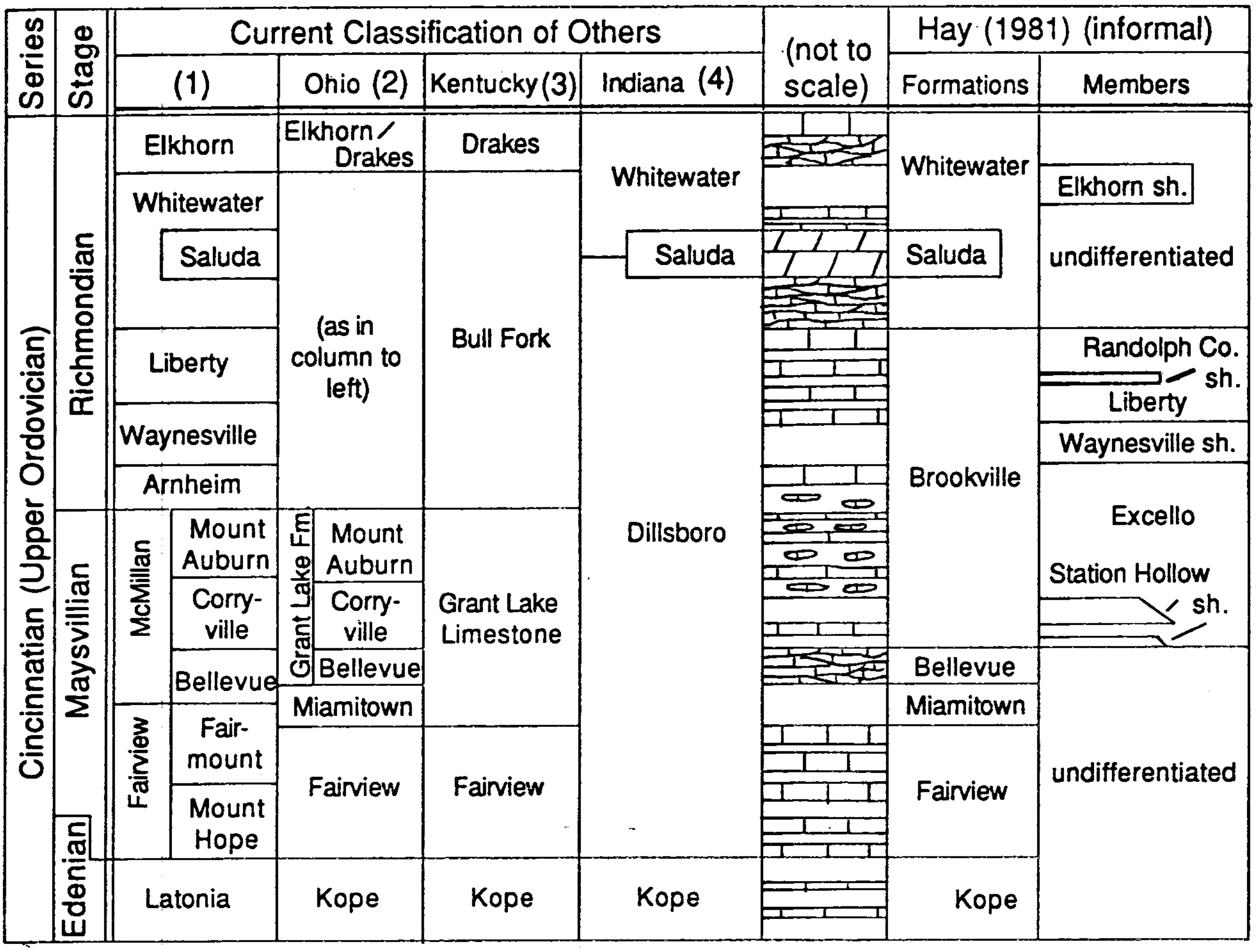

FIGURE 17-3.—Rock-stratigraphic classification (modified from Hay, 1981, and Hay and others, 1981). In the "current classification of others," (1) = Caster and others (1955) and Davis (1992). (2) = Kope from Weiss and Sweet (1964); Fairview and Miamitown from Ford (1967); Grant Lake Formation and members upward from Schumacher and others (1991). (3) = Peck (1966). (4) = Brown and Lineback (1966) and Gray (1972).

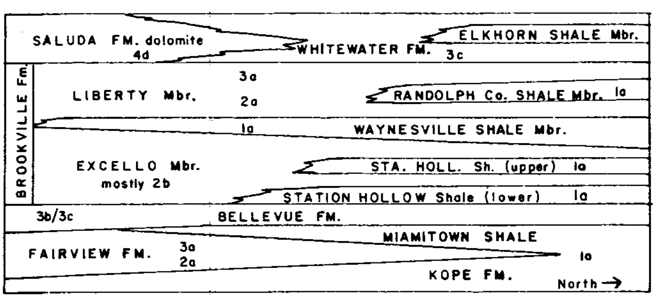

FIGURE 17-4.—Generalized south-north distribution of formations and members as identified in this paper. The Bellevue Formation of the diagram is the Bellevue Member of the Grant Lake Formation as used by Schumacher and others (1991). Modified from Hay (1981) and Hay and others (1981).

(facies 3b and/or 3c), and I suggest recognition of a new formation, the "Brookville formation," for the interval of variable lithology between the Bellevue and the Whitewater or the Saluda, whichever is lower in a given section. The "Brookville formation" can be divided into facies intervals that could be considered members or tongues: the "Excello member," the Waynesville Shale Member, the Liberty Member and the "Randolph County Shale member." Within the "Excello" there are two shale tongues (>70 percent shale) called the "Station Hollow shales." In 1981 I believed these shale tongues merged in the vicinity of the Miamisburg core and therefore called them tongues of the same unit. In view of new information in nearby cores, I now think these are two separate shale wedges and should not be made a single member of the "Brookville formation," although they should be identified in the description of cores and outcrops because of what they can show about sedimentation patterns in the area. The "Station Hollow shales" are at least in part equivalent to the Corryville Member of the Grant Lake Formation in Ohio. The "Excello" includes the Corryville and Mt. Auburn Members of the Grant Lake Formation and the Arnheim formation of Ohio nomenclature. The "Excello" consists of a variety of facies, mostly of groups 2 (55-70 percent shale) but including some group 3 (<55 percent shale), and mostly in "b" or "c" divisions (limy shales and/or rubbly limestones). Overall, the greatest volume of the "Excello" is facies 2b.

The Waynesville-Liberty interval is characterized by decreasing shale percentage upward. On the basis of the descriptions of their cores, the Ohio Division of Geological Survey seems to put the contact approximately where the shale percentage drops below 55 percent, which correlates with my boundary between facies 2a and 3a. I prefer to place the Waynesville-Liberty contact lower in the section so that the Liberty includes facies of Group 2, mainly 2a, as well as 3a, and limits the Waynesville to the predominantly 1a facies. This placement seems reasonable in view of the fact that the Liberty, as here defined, includes the same facies sequence as the lithologically similar Fairview Formation, facies 2a overlain by 3a. This placement makes the Waynesville Shale Member comparable in facies to the Miamitown and "Station Hollow shales" wedges that underlie and overlie the Bellevue, respectively. Unfortunately, at the present time, I do not know where this 70 percent-shale boundary occurs in the Ohio cores, so I cannot relate the Waynesville-Liberty boundary in those cores to its placement based on the 70 percent-shale criterion. Within the Waynesville Shale Member, as defined here, there is a thin but widespread interval of facies 2a or 3a. It would also be useful to know where this interval falls within the Ohio cores, because it constitutes a useful datum for regional correlation.

In the Randolph County and Wayne County cores, and possibly in the Miamisburg core, a tongue of facies 1a (>70 percent shale) within the Liberty has been called the "Randolph County Shale member." Inspection of the Ohio Survey cores, particularly those in the north, should make it possible to identify this shale tongue. It probably is within the upper part of their Waynesville Formation.

In summary, the "Brookville formation" consists of shale wedges—the "Station Hollow shales" in the "Excello member," the Waynesville Shale Member, and the "Randolph County shale member—that lie between the intervals of lower clastic ratio, the "Excello" and Liberty Members. Most of the "Excello" and the Liberty consist of facies in groups 2 and 3. The "Excello member" generally has limy shales and some rubbly limestones of facies 2b and, less commonly, 3b or 3c. The Liberty Member is predominantly facies 2a in the lower part and 3a in the upper part, a decrease in shale upward. The "Excello member" differs from the Bellevue and Whitewater Formations in that most of it is within the 55-70 percent shale range, whereas the Bellevue and the Whitewater have much less shale, placing them in facies of group 3 (3b and/or 3c). This facies division of the "Brookville formation" is useful because it identifies shale tongues and facies sequences that are significant in understanding the geologic history of the area. Finally, the Elkhorn Shale member, a tongue of facies 1a within the Whitewater Formation, is informally proposed as a member of the Whitewater Formation. In Preble County (Ohio) core 3023, the Elkhorn Shale was identified as an informal unit above the Whitewater, with undifferentiated Upper Ordovician strata above it. The nearby Richmond outcrops (see paper 15 in this volume) and the Wayne County core contain Whitewater rubbly lithology (cemented with dolomite) as well as some other facies above the Elkhorn Shale member, so it seems reasonable to extend the Whitewater Formation to the top of the Ordovician, at least in this area.

DEPOSITIONAL ENVIRONMENTS OF LITHOFACIES

Interpretation of depositional environments depends on the characteristics of individual facies and on their stratigraphic relations as revealed in transition and probability matrix analysis (Hay, 1981). The matrix analysis gave the probability that each facies would be overlain by each other facies and compared that result with the probabilities if the facies sequence were random. This was done for one-step transitions and for reversible two-step transitions, for example, 1a overlain by 2a overlain by 1a. The geological significance of facies successions that are in conformable vertical contact is that they represent adjacent depositional environments (Walther's Principle; Blatt and others, 1972, p. 187-188). The environmental conditions responsible for some facies are relatively easy to interpret on the basis of individual facies characteristics. For others, the evidence is less clear, and intepretation must rely heavily on the association of these facies with those that are less ambiguous. This discussion of facies associations and environments is followed in the next section by isopach maps of formations and members. The combined information makes it possible to interpret paleogeography and history of these Cincinnatian rocks.

INTERPRETATIONS OF FACIES OF GROUPS 3 AND 4

Figure 17-5 shows schematically the suggested lateral relations of the lithofacies based on facies associations and characteristics. The facies for which environmental interpretations are least ambiguous are those of group 4, all of

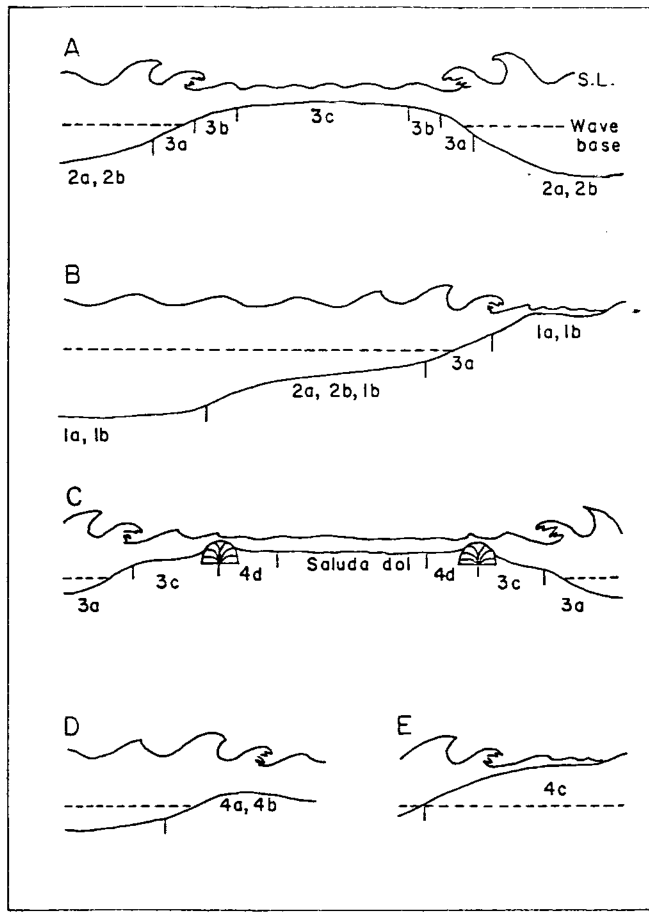

FIGURE 17-5.—Possible depositional environments and lateral relations of facies. From Hay (1981) and Hay and others (1981). Fan-shaped symbol in diagram C represents *Tetradium* colonies. Approximate lateral scale for diagrams A, B, and C is tens of miles; for diagrams D and E, a few hundred or a few thousand feet. S.L. = sea level; Saluda dol = Saluda Formation; 1a, 1b, 2a, etc. are lithofacies types diagnosed and illustrated in figure 17-2.

which probably indicate very shallow water. Facies 4d is the most significant of these because it is widespread and allows interpretation of the strongly associated facies in group 3, particularly 3c, the rubbly rock of the Whitewater Formation. Facies 4d, exposed at Garr Hill (IN-FR-0003; see paper 11 in this volume) near the top of the Brookville composite section about 4 miles (6.4 km) north of Brookville, Indiana, is a thoroughly burrowed, micritic limestone with very little shale. It contains algae in which the structure is preserved and a fauna of ostracodes and small snails but lacks the normal marine fauna of bryozoans, brachiopods, and echinoderms characteristic of most of the Cincinnatian. It is underlain by massive *Tetradium* colonies that are a part of the Saluda Formation described by Hatfield (1968). Farther south and west in Indiana, facies 4d is overlain by Saluda dolomite containing mud cracks. Hatfield (1968) thought that the *Tetradium* masses ringed and acted as a wave baffle for a shallow and intermittently exposed lagoon in which the dolomite formed. The stratigraphic position and fossil characteristics of facies 4d suggest that it formed in quiet, very shallow, probably somewhat hypersaline water just lagoonward of the baffle. The Garr Hill outcrop is near the northern margin of the Saluda, and no dolomite occurs there (Hay and others, 1981). Facies 4d is overlain by, and in some cases interbedded with, facies 3c, the rubbly Whitewater; therefore, facies 3c must have formed in a laterally adjacent environment (fig. 17-5C) that was only slightly deeper, but, as the diverse fauna indicates, the water was of normal marine salinity.

Although formed in shallow water, facies 3c probably was deposited under relatively low energy conditions compared to 3b and 3a, with which it is stratigraphically associated. Both its field characteristics and limestone thin sections support this interpretation. Of the limestones studied, 60 percent of the facies 3c thin sections are micritic compared with 26 percent for facies 3a, and 71 percent of the facies 3c limestones are rudites compared with 50 percent for facies 3a. With the exception of the horn corals, which may be biochemically eroded, the fossils of facies 3c are not significantly abraded, brachiopods are commonly articulated, and molluscan steinkerns are abundant. These factors are consistent with a relatively quiet environment, as is the poor separation of the fine clastics and carbonates into discrete beds. Such conditions could occur on the interior of a shallow platform as illustrated in figure 17-5A. Marginal to this platform, under higher energy conditions, facies 3b and 3a could have formed as illustrated. This distribution is analogous to the facies distribution of the Bahama Bank (Imbrie and Purdy, 1962), where higher energy environments are marginal to the bank.

The major facies of the Bellevue is facies 3b, which has thin planar or wavy carbonate beds separated by thin fossiliferous shales and rubbly limestones. The Bellevue environment, although similar to that of the Whitewater facies 3c, was shallow but more strongly agitated, at least when the sediments of the more laterally continuous, less rubbly limestone beds were deposited.

Facies 3a, which has planar limestones and blocky or fissile, relatively unfossiliferous shales, is characteristic of the upper part of the Fairview and Liberty. This facies probably was deposited below normal wave base but periodically was subjected to agitation by storm waves and strong currents that separated the coarser biogenic debris from the fine clastics, thereby producing the limestone beds, and at least the lower part of the overlying shale, as current velocity decreased.

The concept of storms as a mechanism for producing the interbedded limestones and shales of the Cincinnatian is supported by the fact that the lower bedding surfaces of the limestone beds commonly are in sharp contact with the underlying shales, but the tops of the beds are commonly silty or gradational with the overlying shales. The siltstone beds that commonly are interbedded with shales (for example, in the Fairview and the lowest part of the Waynesville) also are likely to be the result of storms that sorted the silts rather than biogenic debris from the muddy sediments. Surely these thin siltstones are best explained as the result of localized mechanical separation of the coarser grains of the muds and not by periodic influx of silt from a distant source area. There is no evidence that individual siltstone layers thicken in any particular direction or can be traced to any source area. Therefore, the siltstones and at least many of the limestones have a similar origin. In addition, the broad lateral extent of the limestone beds compared to their thinness strongly suggests that storms played an important role in their final characteristics and burial by spreading into thin sheets any localized biogenic buildups.

Meyer and others (1981) described another possible way in which storms may have influenced the sediments. Terrigenous clastics suspended by storms may have been carried to nearby localities and deposited on top of the shelly substrate and living organisms without producing any significant reworking of the carbonate debris. The characteristics of the limestone beds in this case would depend on whether the biogenic material had been reworked prior to the event that buried it.

INTERPRETATION OF FACIES GROUPS AND THE SHALE PROBLEM

A major problem or ambiguity in facies interpretation arises when one considers the cause of changes in clastic ratios that distinguishes groups 1, 2, and 3. A change in clastic ratio can be caused by a change in the sedimentation rate of terrigenous clastics, by a change in the rate of production of carbonates, or by both. The sedimentation rate of clastics can be a function either of rate of supply from the source area or of hydrodynamic conditions in the basin. The rate of biogenic-limestone production can be influenced by water depth, substrate texture (softness), turbidity, or variation in chemical conditions such as salinity or Eh, all of which may affect the density and diversity of carbonate-producing organisms.

The question of interpretation is complicated further by uncertainty about the conditions under which muds are deposited. The traditional view for shales, such as those in the Cincinnatian of Ohio and Indiana that were deposited tens to hundreds of miles from land, is that sedimentation of the muds took place under relatively low energy conditions. Pryor's (1975) work on modern muds suggests that flocculation and biogenic pelletization may cause the clays and silts to behave more like sand particles. If this idea applies to the Ordovician shales, then there may have been very little difference in the energy levels responsible for the shales and the sand-sized allochems that are common constituents of the limestones.

Another traditional view about the shale-rich intervals such as the Miamitown Shale, the Waynesville Shale Member, and the Elkhorn Shale member is that they were deposited at greater depth than the enclosing limestone-rich intervals. This view probably is true for some of the Cincinnatian shales but not for all. Each of these shale tongues needs to be interpreted individually. A facies sequence of 1a, 2a, and 3a upward such as the Kope through the Fairview, or the 2a to 3a transition upward in the Liberty, probably indicates shoaling-upward conditions. The fact that the Kope is quite uniform and thick over a large geographic area suggests a stable, relatively deep water environment. The limestone content increases near the top of the Kope where it grades into the Fairview, probably as a consequence of progressive shoaling. Figure 17-5B illustrates this interpretation of lateral relations of these facies as well as an alternative environment of very shallow water for facies 1a.

When facies 1a or 1b is in direct contact with those of group 3, it may not be appropriate to attribute the facies change to an abrupt change in water depth. The Elkhorn Shale member may be an example of this situation in which an influx of clastics, or a difference in water chemistry, rather than a change in water depth, is a more reasonable explanation for the facies change.

I believe that the contact between the Waynesville Shale Member and the "Excello member" is a disconformity; if so, the Waynesville Shale Member, at least in the lower part, probably was deposited in very shallow water. In most localities the contact between the "Excello" and the Waynesville is sharp and involves an abrupt lithologic change. The upper part of the "Excello" is nodular or rubbly limestones and limy shales of facies 1b or 2b. In many localities these facies are overlain by a few feet of facies 3a with brown, sandy-textured, friable sediment between fairly well sorted limestone beds. These brown beds owe their texture to sand-sized, phosphatized steinkerns of minute brachiopods, mollusks, and other small fossils. This band of facies 3a is commonly oxidized, even in cores; this oxidation suggests it may be the top of the regressive phase of the "Excello" and lies just below the disconformity. On the other hand, this 3a band may be the basal unit of a transgressive Waynesville cycle. The basal beds of the Waynesville are facies 1a shales with interbeds of siltstone, rather than limestone, and very few fossils. The Waynesville Shale Member becomes more fossiliferous upward. To the north, in the Randolph County, Wayne County, and Preble County (3023) cores, the contact is somewhat less sharp, but throughout the region this contact is the most consistently abrupt lithologic change in the Cincinnatian. Cumings and Galloway (1913) noted an abrupt faunal change at this contact, where about 30 species of bryozoans either disappear or appear; this faunal change, they said, is greater than at any other stratigraphic horizon in the Cincinnatian. The proper assignment of the 3a zone that I placed at the top of the "Excello" probably could be determined by a study of the bryozoans within it. So the interpretation of a disconformity is supported both by faunal and lithologic evidence, although the precise position of the disconformity is not certain.

If the barren shales and siltstones at the base of the Waynesville represent the basal beds of a transgression, then the sediments must have been deposited in very shallow water unless the transgression was extremely rapid. Unlike the Kope, this occurrence of facies 1a would not be a deep-water deposit. The scarcity of fossils may be due to abnormal water chemistry or a high rate of mud sedimentation that created turbid or otherwise unstable conditions, possibly an unusually soft, soupy substrate. As the transgression proceeded, water depth increased, as did the biological diversity. The gradual increase in fossil diversity and abundance argues against a rapid transgression and deposition of the Waynesville sediments in deep water. Linguloid brachiopods are common in the lower part of the Waynesville, and their presence also suggests a shallow-water environment (Hay and others, 1981).

The fauna of the upper part of the Waynesville Shale Member (as limited here to facies 1a) has characteristics in common with the upper part of the Kope (Hay and others, 1981) and may have formed at similar depth, although this is not the only possible explanation for the similarity of the fossil assemblages. They both may have been controlled by turbidity or substrate texture rather than depth. The fine clastics of the Waynesville shales may have been derived from weathering and erosion of a low landmass exposed during the hiatus as well as from source areas to the east and southeast, the likely source of most of the Cincinnatian terrigenous clastics. The disconformity may not exist in the northern cores where the contact is somewhat less abrupt than elsewhere. This contact is well exposed near the base of both the new Indiana Route 1 road cut at South Gate Hill (IN-FR-0005) and Bon Well Hill (IN-FR-0001) (see papers 10 and 12 in this volume).

In summary, the facies with >70 percent shale, those of group 1, may have formed in a variety of environments. The difference between facies 1a and 1b, which has more limy shales and/or nodular rubbly limestones, may be in the degree of effectiveness of storms in segregating the biogenic debris from the finer clastics; if so, facies 1a would have resulted when sorting was effectively accomplished. Facies 2b, for example, in the upper part of the "Excello," is quite similar to facies 3c of the Whitewater except that it contains more shale. It may be that the supply of clastics was greater when the "Excello" sediments accumulated.

REGIONAL ISOPACH AND STRUCTURE-CONTOUR MAPS

Isopach and structure-contour maps (figs. 17-6 through 17-8) show a tentative regional picture that is very likely to be revised as more information from the Ohio Division of Geological Survey is incorporated. To the extent possible based on available descriptions, these maps include information from Ohio Survey cores 2537 (D. A. Stith and E. M. Swinford, written and oral commun., 1983, 1991), 2627 (Shrake and others, 1990), 2981, 2982, 2984, and 3023. There are problems in attempting to incorporate information from these new cores that relate to illustration of isopachs for intertonguing facies and a lack of information on placement of boundaries for units within the "Brookville formation."

The structure-contour map for the base of the Fairview Formation (fig. 17-6B) shows patterns similar to those of the base and top of the "Brookville formation" (Hay, 1981) that reflect post-Ordovician deformation.

ISOPACH MAPS OF THE FAIRVIEW, MIAMITOWN, AND BELLEVUE

Figures 17-6C, 17-6D, and 17-7A are isopach maps for the Fairview Formation, the Miamitown Shale, and the

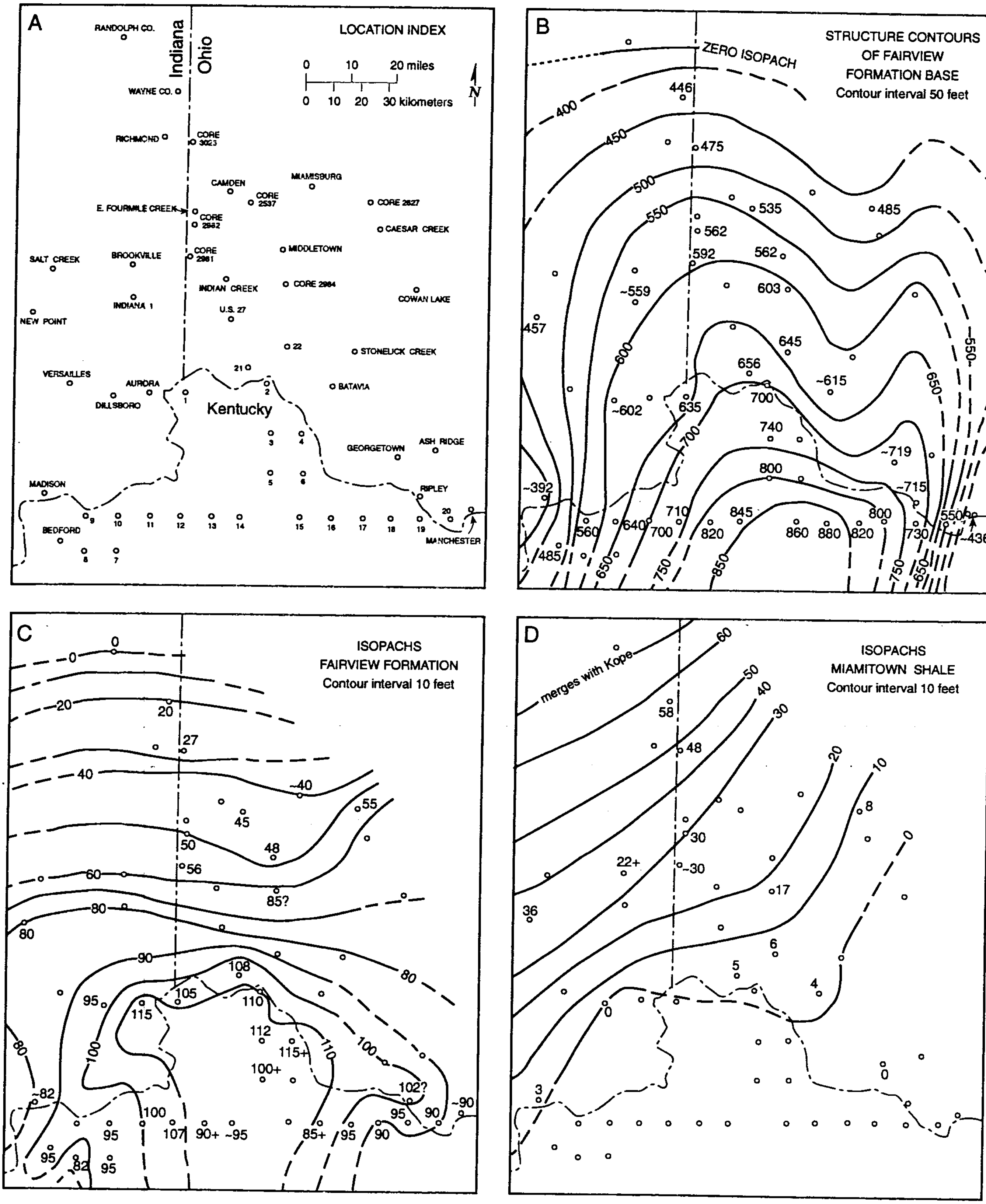

FIGURE 17-6.—Index map (A), structure and isopach maps of the Fairview Formation (B, C), and isopach map of the Miamitown Shale (D). Modified from Hay (1981). The value (85?) for core 2984 on C is plotted but not contoured.

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SAMPLING THE LAYER CAKE THAT ISN'T: THE STRATIGRAPHY AND PALEONTOLOGY OF THE TYPE-CINCINNATIAN

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