# STRATIGRAPHY OF THE UPPER ORDOVICIAN KOPE FORMATION IN ITS TYPE AREA (NORTHERN KENTUCKY), INCLUDING A REVISED NOMENCLATURE

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## INTRODUCTION

A well-developed stratigraphic framework is a necessary condition for detailed analysis of sedimentary processes in ancient rock units. Although the stratigraphy of Upper Ordovician strata of the Greater Cincinnati region has been studied for many years, studies of process sedimentology are still limited by a less-than-thorough understanding of the fine-scale stratigraphy of these units. Early on, the rocks of the classic Cincinnatian Series were subdivided using a mixed biostratigraphic and lithostratigraphic approach (Bassler, 1906; Ulrich and Bassler, 1914). These early workers were interested in establishing a regional time framework within which to examine primarily faunal changes. Although these workers clearly recognized the existence of local facies changes, their views on the lateral continuity of lithofacies and biofacies in some cases led to correlation errors.

In recent decades, the application of a facies model approach has contributed to a paradigmatic view of the stratigraphic record as a mosaic of local lenticular sedimentary bodies with little lateral continuity and little or no relationship to similar appearing beds in other sections. Earlier attempts to link together marker horizons in the Cincinnatian Series into a regional framework were viewed with suspicion and commonly were castigated as antiquated "layer-cake stratigraphy," although in many cases such efforts were based on strong empirical evidence. Many of the classic named units of the Greater Cincinnati area were subsequently abandoned as stratigraphers in adjoining regions developed a plethora of local terms based on a perhaps overly zealous attempt to make stratigraphy strictly "lithostratigraphic." A complex mosaic of terms came to be applied to the same set of rocks (e.g., Cuffey, 1998; Fig. 1). Even today the states of Ohio, Kentucky, and Indiana have distinct sets of names for strata that are arguably the same. In the process, the interest in temporal relationships and depositional processes recorded in the stratigraphic record were sometimes eclipsed (see Holland, 1993, for discussion).

With its renewed emphasis on throughgoing discontinuities and condensed beds, sequence analysis has encouraged a broader, more regional view of stratigraphy and an attempt to understand the genetic significance of particular beds and surfaces. To some degree it vindicates the earlier view of the Cincinnatian Series as exemplifying "layer-cake stratigraphy." Sequence stratigraphy, originally developed from remote seismic studies of passive margin sediment wedges, is now being applied at an outcrop scale to diverse depositional systems including foreland basins such as the Appalachian (or Taconic) basin of the Ordovician and Silurian periods (Brett et al., 1990 a,b; Witzke et al., 1996; Brett et al., 1998).

Although a number of authors have recently attempted to recognize small-scale cycles within the Kope Formation in its type area, there has been little attempt to correlate these beyond the immediate area of Cincinnati (i.e., the area circumscribed by the I-275 ring highway). However, early efforts at correlation of event horizons within this core area have led to promising results. For example, Jennette and Pryor (1993) were able to recognize event beds, such as a distinctive gutter cast horizon and

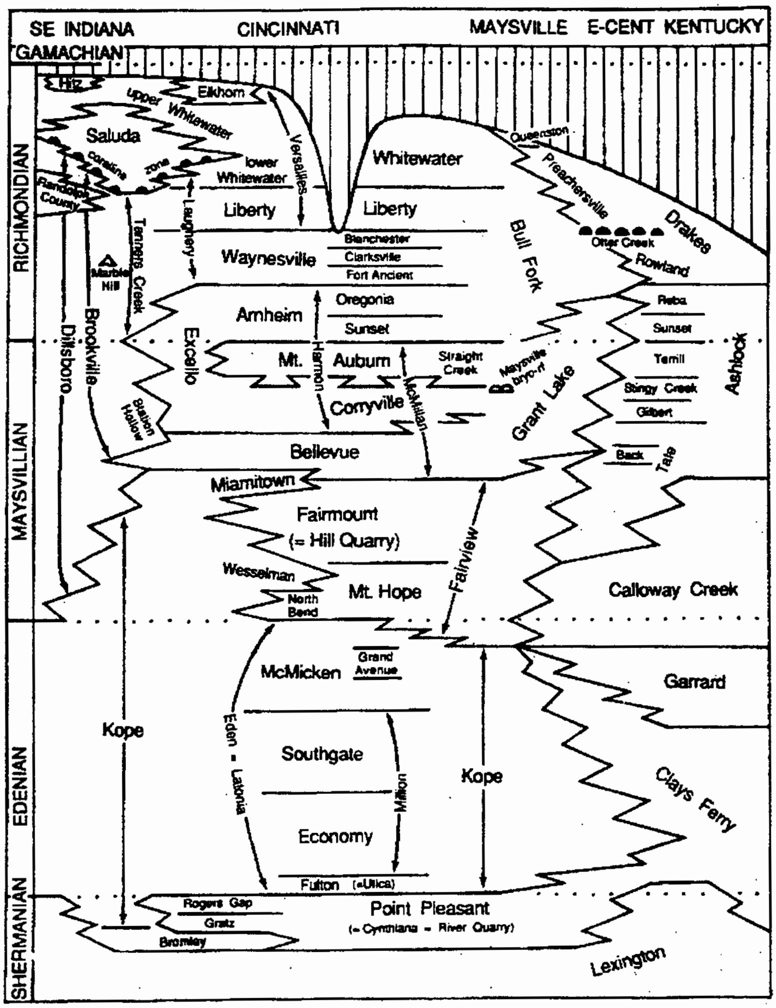



**Figure 1.** Correlation chart of Upper Ordovician Cincinnatian Series for the Ohio-Kentucky-Indiana area. From Cuffey (1998).

a band of siltstone beds containing a distinctive morphotype of *Diplocraterion* burrows, widely across this area (see Fig. 8, p. 70, this volume). In a similar vein, Datillo (1994) recognized a distinctive set of marker beds and faunal cycles that permitted detailed correlation of the somewhat younger Miamitown Shale in outcrops and drill cores from this area (Fig. 10, p. 42, this volume). However, there have been few attempts at fine-scale correlation (i.e., at the level of bundles of beds or even single-event beds) over an area extending beyond the core region of Cincinnati. This, however, represents the next challenge: to trace individual beds and sets of beds from the Cincinnati core area outward in directions both parallel to and perpendicular to depositional strike.

The AA Highway in northern Kentucky provides a cross-section of a mixed siliciclastic-carbonate ramp, from slightly deeper, more distal, shale-dominated facies to the northwest (i.e., near Cincinnati) to shallower, somewhat more proximal, carbonate-dominated facies to the southeast (i.e., near Maysville; Fig. 2, p. 35, this volume). The roughly NW-SE orientation of the AA Highway was previously thought to be normal to the NE-SW-oriented Sebree Trough located north and west of the Cincinnati area and, hence, approximately perpendicular to inferred depositional strike (e.g., Mitchell and Bergström, 1991; Ettensohn, 1992a; Fig. 3, p. 35, this volume). However, recent paleoegeographic refinements suggest that the Sebree Trough had an embayment to the southeast of Cincinnati (Ettensohn, in press). The southern boundary of this embayment was aligned along a NW-SE-oriented lineament, approximately parallel to a deep-seated fault and subparallel to the Ohio River (Ohio-Kentucky border) from Cincinnati to slightly southeast of Maysville. The local depositional dip along this portion of the ramp would have been to the northeast and depositional strike would have been northwest-southeast. With this reconstruction, the Ohio-Maysville axis of the AA Highway would be oriented more nearly parallel to facies strike.

Detailed stratigraphic analysis of the Kope Formation may provide a test of these alternative paleogeographic models. If the older, simpler model of NE-SW-oriented depositional strike is correct, major across-strike facies and thickness changes would be anticipated in the Cincinnatian Series along the AA Highway transect. Conversely, if the embayment model is correct, then Cincinnatian Series facies and thicknesses should be relatively uniform along the AA Highway, facilitating stratigraphic correlation. We have utilized the large number of relatively fresh exposures along the AA Highway and adjacent regions to refine the stratigraphy of the lower Cincinnatian Series, especially that of the Kope Formation, and to test these alternative paleogeographic models. In this paper, we review and update aspects of the stratigraphy of the Kope Formation and associated units, establish a more detailed framework for future depositional process studies, and consider implications of our stratigraphic work for an understanding of the paleogeographic setting of the Cincinnatian Series.

## DETAILED SUBDIVISION OF THE KOPE FORMATION

In our recent studies, we have undertaken a detailed subdivision of the Kope Formation, starting from a well-studied 60-m-thick reference section, a composite of outcrops at KY Rte. 445 and along I-275 near the Ohio River (Holland et al. 1997; Fig. 5, Holland et al., this volume). The Kope Fm. is well-exposed in these sections, although the lowermost ten or so meters of the formation is missing here. We will visit the KY Rte. 445 section, which near its junction with Kentucky Rte. 8 (Stop 1 on Sunday; Fig. 23, p. 29, this volume). These sections were previously studied in detail from the standpoint of biostratigraphy by Mitchell and Bergström (1991), who obtained numerous graptolite samples and recognized the *Climacograptus spiniferus* (*Geniculograptus typcalis*)-*Geniculograptus pygmaeus* zonal boundary about 40 m above the base of the Rte. 445 roadcut (Figs. 3-4). Subsequently, Holland et al. (1997) made detailed measurements and faunal censuses and defined a series of 40 meter-scale cycles within this 60-m-thick composite section. Despite different approaches and minor discrepancies, these two groups of researchers produced generally similar measured sections.

We independently examined the composite reference section and identified a series of potentially traceable beds and intervals, the stratigraphic positions of which were determined in relation to the numbered cycles of Holland et al. (1997) and to prominent beds shown in the outcrop profile diagram of Mitchell and Bergstrom


**Figure 2.** Area of new Composite Reference Section (CRS) for the Kope Fm., established herein. The CRS includes sections at Duck Creek, KY Rte. 445, and I-275. This area is just SE of Cincinnati, along I-275 as it approaches the Ohio River from the west. Portion of U.S.G.S. Newport, Ky Quadrangle sheet (scale 1:24,000); area shown is about 1.5x2.5 miles.

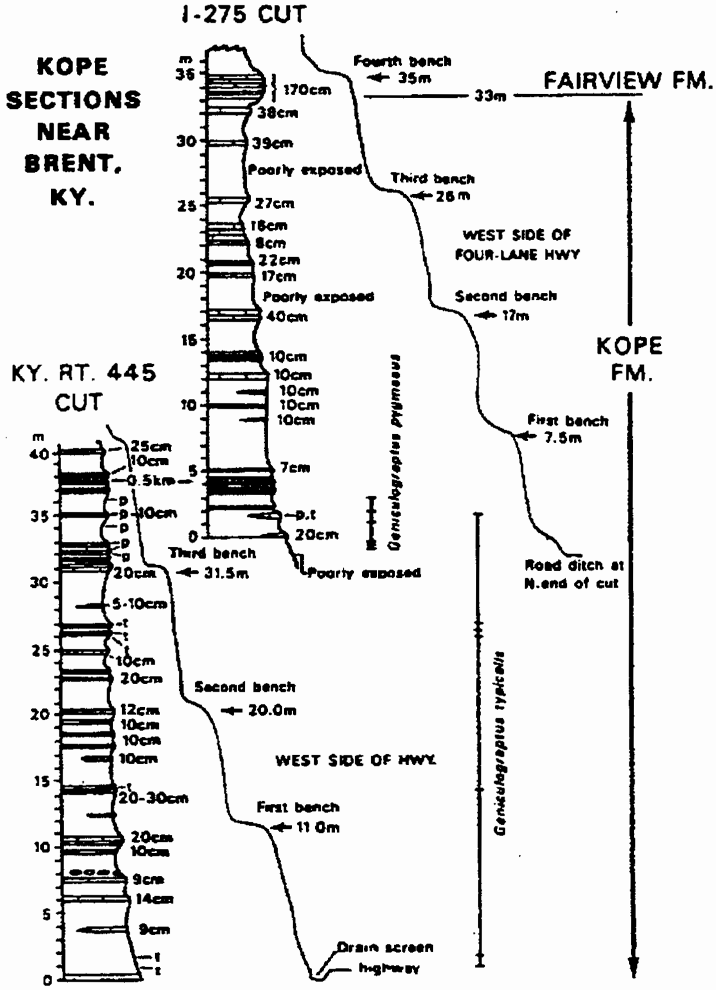


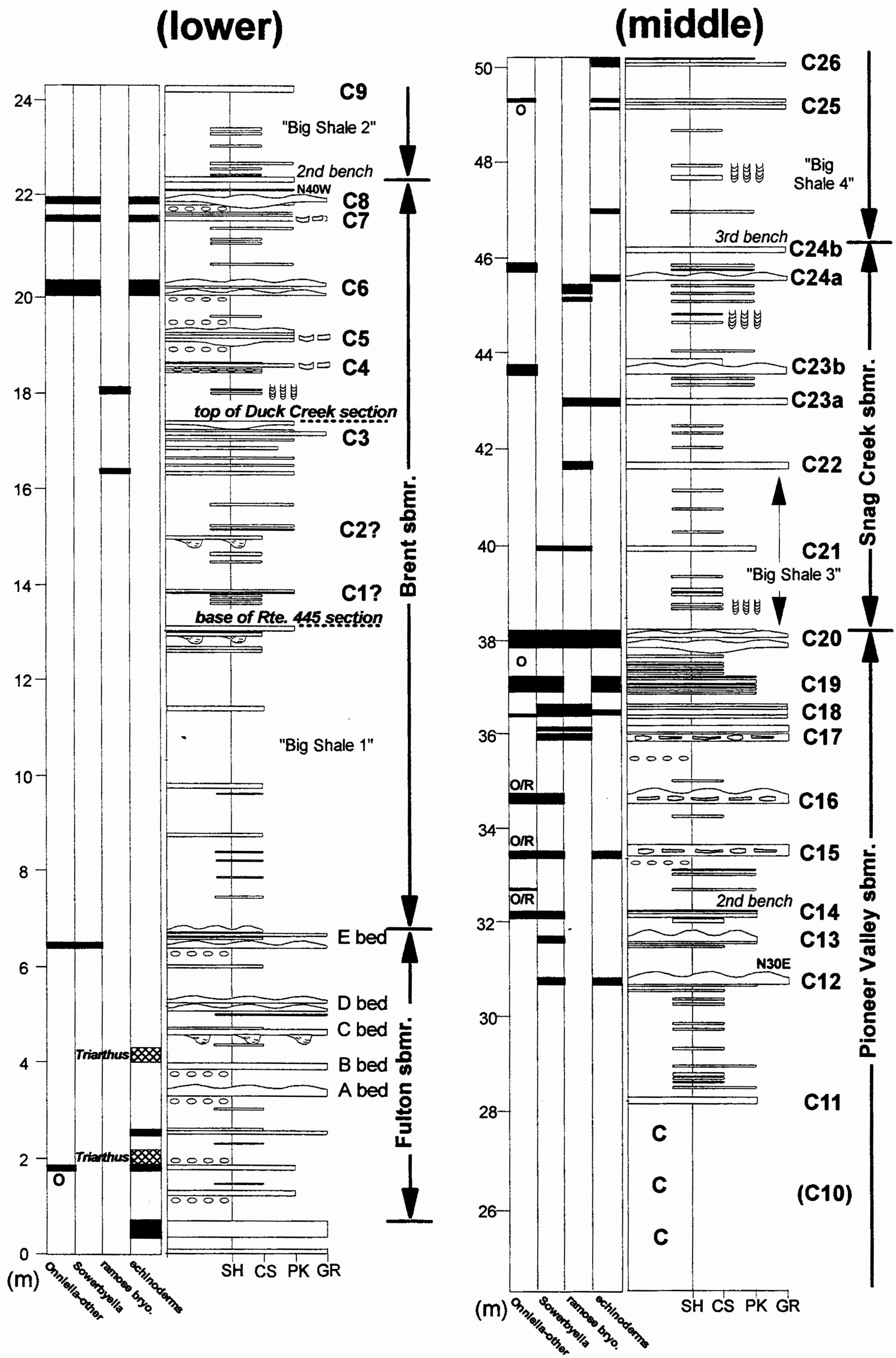

**Figure 3.** Vertical ranges of graptolite species at the Rte. 445 and I-275 composite section at Brent, Kentucky. Modified from Mitchell and Bergström (1991). This is the same as the Kope reference section of Holland et al. (1997; Fig. 5, p. 100, this volume).

**Figure 4.** Graptolites (*Geniculograptus* cf. *G. typicalis*) in calcareous shale from Snag Creek submember (Southgate Member of Kope Fm.); outcrop behind Kentucky emissions-check station off Rte. 17 ("White Castle site"), Covington, KY. Field of view ca. 5x8 cm.

(1991). Beds were numbered in accordance with the numbering scheme of Holland et al.'s (1997) cycles, and, in most cases, the prominent marker limestone beds that we recognized correspond to the tops of Holland et al.'s cycles. Regardless of whether or not sedimentary cyclicity is present in this reference section, these prominent marker beds do display distinctive features and stacking patterns that together can be used as a template for regional correlation studies. In addition, we located a section of the upper Point Pleasant Fm. and the basal 15 m of the Kope Fm. in Duck Creek, about 1.5 km south of the Rte. 445 section (Fig. 2). Beds near the upper end of this section overlap with those at the base of the Rte. 445 roadcut. Splicing this new section with the existing Rte. 445 section has yielded a new Composite Reference Section (CRS) for the entire Kope Formation, presented herein (Fig. 5).

Recognition of specific marker horizons is facilitated by features such as unusual or distinctive faunal elements, trace fossil horizons, taphonomic features, and sedimentary structures. Certain trace fossil horizons are very useful at a regional scale, e.g., Jennette and Pryor's *Diplocraterion* bed (see discussion in 3rd Brett and Algeo paper, this volume). With respect to the utility of taphonomic features, an example is a bed within the middle Kope Fm. (bed 25) containing abundant, highly abraded frag-

# Composite Reference Section



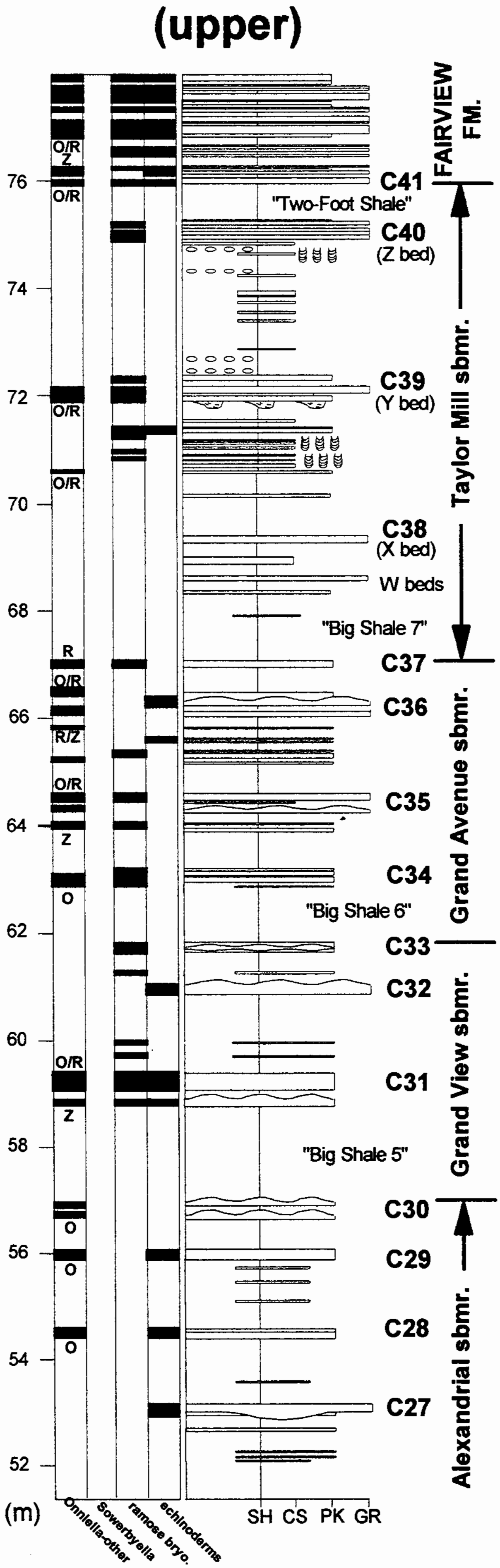
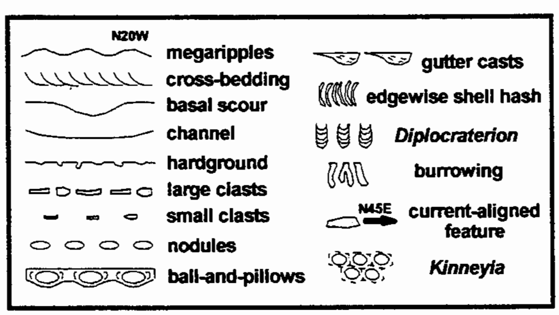



**Figure 5.** New Composite Reference Section (CRS) for the Kope Formation in the Greater Cincinnati area. This section combines (1) the existing Rte. 445 reference section of Holland et al. (1997; their fig. 5, p. 100, this volume), itself a composite based on outcrops along KY Rte. 445 and I-275 near the Ohio River, and (2) a newly measured section of the upper Point Pleasant Limestone and basal Kope Formation along Duck Creek, about 1.5 km south of the Rte. 445 section. (Fig. 2). We tied these sections at the top of a set of thin limestone ledges (cycle 3 of Holland et al.) that are underlain by three meters of shale, calcisiltites, and very thin packstones. This results in about four meters of overlap between sections (at 13-17 m in the CRS) and suggests that ca. 13 m of basal Kope are missing in the Rte. 445 reference section. Note that we have redrawn the Rte. 445 portion of our new CRS based on the original field sections and notes of S. Holland, A. Miller, and D. Meyer in conformance with the style of the other measured sections presented in this field guide. As for all measured sections herein, the four-part column at left shows dominant components of skeletal grainstones and packstones: O = *Onniella*, R = *Rafinesquina*, Z = *Zygospira* (col. 1), *Sowerbyella* (col. 2), ramose bryozoans (col. 3), and echinoderms (col. 4). In the main stratigraphic column, column width represents lithology: SH = shale, CS = calcisiltite, PK = packstone, and GR = grainstone. Beds are labeled per the stratigraphic nomenclature of Brett and Algeo (Table 1, p. 55, this volume). Beds inferred to be correlative with capping beds of cycles in the Holland et al. Rte. 445 reference section are designated by "C" followed by the cycle number; uncertain cycle assignments are indicated by "?", and missing or covered cycle cap beds are enclosed in parentheses.



ments of the brachiopod *Onniella* that are typically blackened and set into a dark grey matrix; these features are uncommon in the Kope, and the bed is itself is widely traceable on this basis. Certain stratigraphic intervals can be distinguished by "taphonomic" features, e.g., a series of beds in the upper middle Kope Fm. (beds 26-30) is characterized by red-weathering *Onniella* brachiopod valves which are relatively complete and only show minor fragmentation; although this discoloration may be of post-depositional rather than taphonomic origin, it nonetheless represents a characteristic useful in correlation. Further, horizons of small carbonate nodules or concretions that show a distinctive pattern of occurrence provide useful fingerprints for particular parts of the section. Sedimentary structures or features such as megaripples, gutter casts, rip-up clast layers, or beds of reworked concretions also provide distinctive marker horizons.

Distinctive features of faunal distribution could also be related to the framework of marker units, and to earlier defined (but now sometimes disregarded) three members of the Kope Formation: the Economy, Southgate, and McMicken members (Bassler, 1906; Davis, 1994). For example, the brachiopod *Sowerbyella rugosa* (Fig. 6A) was found to be exceedingly abundant in a series of limestones up to about 25 m above the base of Kope (up to about bed 18) at the Rte. 445 reference section; this approximates Bassler's (1906) Economy-Southgate boundary. This species shows an abrupt decrease in abundance above this level, although it reappears as scattered abnormally large and broad-hinged specimens in a few thin beds of the Southgate Member. *Onniella* (Fig. 6B) and, to a somewhat lesser degree, *Rafinesquina* are the dominant brachiopods in limestones of the Southgate and McMicken members. Also present in these units are distinctive mollusc-rich shale horizons that had been used in earlier definition of the Southgate Member. Because the faunal changes can be related to objectively defined lithostratigraphic boundaries, we chose to retain the older member names in essentially their

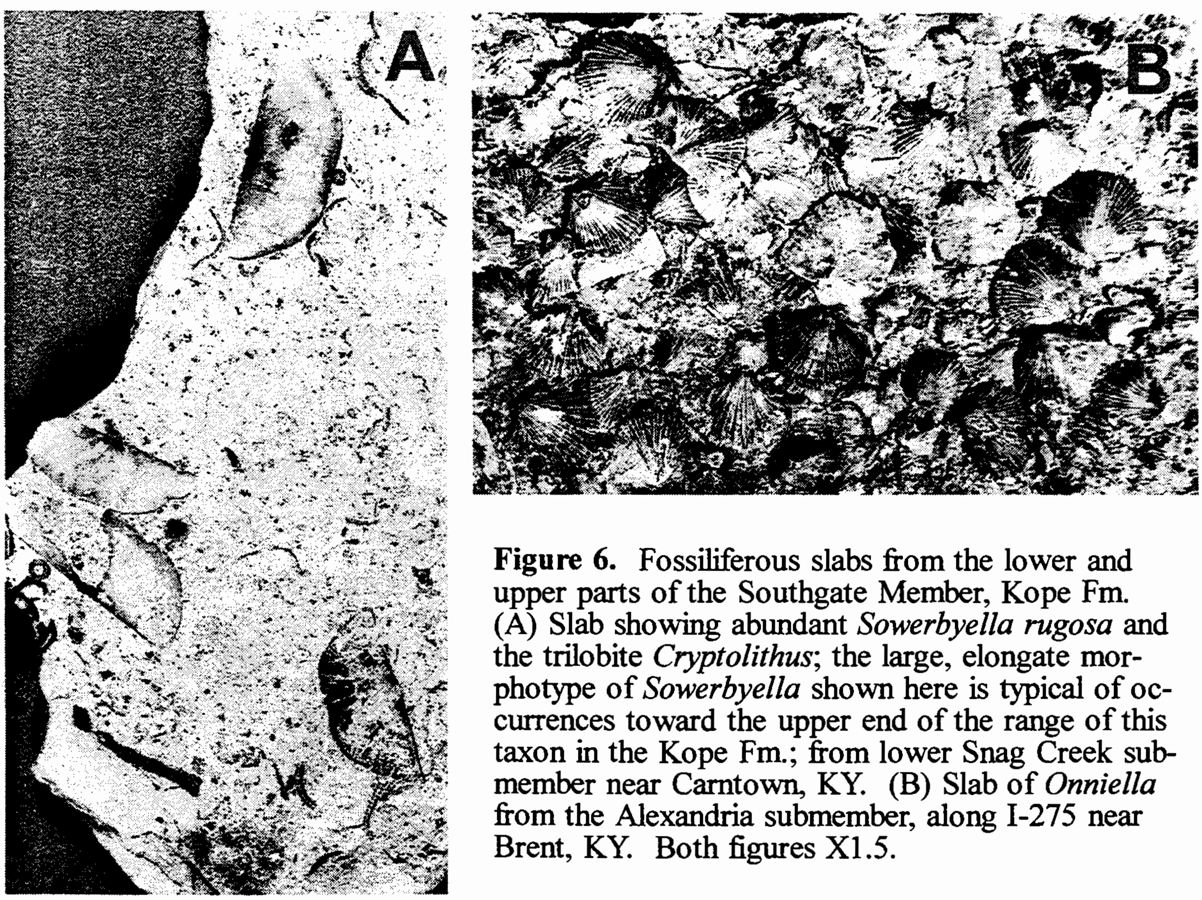



**Figure 6.** Fossiliferous slabs from the lower and upper parts of the Southgate Member, Kope Fm. (A) Slab showing abundant *Sowerbyella rugosa* and the trilobite *Cryptolithus*; the large, elongate morphotype of *Sowerbyella* shown here is typical of occurrences toward the upper end of the range of this taxon in the Kope Fm.; from lower Snag Creek submember near Carntown, KY. (B) Slab of *Onniella* from the Alexandria submember, along I-275 near Brent, KY. Both figures X1.5.

original meanings but with more tightly defined lithostratigraphic boundaries. Inevitably, our research also pointed up some discrepancies, most notably relating to reported thicknesses of the members of the Kope Fm., that have seemingly been carried on in the literature for many years.

We also recognized a series of eight thick (1-7 m) shale-rich intervals ("Big Shales") that were subsequently found to be very useful in establishing broad stratigraphic correlations between outcrops (Fig. 5; Fig. 23, p. 29, this volume). Ultimately, we used the decameter-scale shale-limestone packages defined by these shales to define a series of informally named submembers within the Kope Formation (Fig. 5; Table 1). Our submembers, which are each on the order of 10-20 m thick, commence with the bases of these "Big Shale" intervals. As such, they might be interpreted as shallowing upward cycles or parasequences. But, regardless of their interpretation, we believe that they are objectively defined and useful lithostratigraphic and sequence stratigraphic units. We also found it useful to name a few of the more distinctive beds (Table 1), and other beds were numbered following the scheme of Holland et al. (1997). While, some workers will surely object to the proliferation of names, we found it useful for purposes of communication to have this shorthand method of denoting particular intervals in the Kope. Also, the use of names for beds, or bundles of beds, obviates problems of numerical order that may arise, for example, when additional beds are found to exist in laterally correlative sections between previously numbered units.

## DETAILED CORRELATION OF THE KOPE FM. ALONG THE AA HWY.

Once a series of marker beds and intervals was established in the Rte. 445 reference section, we began studying nearby outcrops and extending detailed bed-by-bed correlations outward (Figs. 7 and 8). Our strategy was to critically examine adjacent sections moving progressively from northwest to southeast, approximately normal to inferred depositional strike, from the vicinity of Cincinnati to the region of Maysville. More than 50 outcrops were examined along the relatively new Kentucky Rte. 9 (Alexandria to Ashland, or AA Highway) over a distance of about 100 km from Alexandria to new exposures on Route 3071, just northwest of Maysville, Kentucky. Major sections were measured to the nearest centimeter with a steel tape and hand level, and a digital altimeter was used to establish the relative elevations of prominent marker horizons in most outcrops. Representative samples of certain marker beds were collected and slabbed to examine lithology and to make within- and between-bed comparisons of fabrics and faunas. Work on correlation proceeded from large-scale features (e.g., the Kope/Fairview contact, the Grand Avenue beds) to intermediate-scale features (e.g., the six "Big Shales" and the submembers that they define) to, finally, fine-scale features (e.g., individual limestone bundles and event beds). Work at the finest level of correlation is still in progress.

A complicating factor in regional correlation is the commonly observed phenomenon of lateral variation of bedding patterns within a single outcrop. Many amalgamated beds show substantial variation in overall thickness, number of components beds, and degree of homogenization at the outcrop scale, e.g., variations in thickness on the order of 10-15 cm are not uncommon over lateral distances of a few meters or tens of meters. Clearly, many of these beds have complex histories and their final appearance is the net result of multiple episodes of reworking including, in some cases, particularly severe events that occurred toward the end of their depositional history. Although some beds, even thicker amalgamated units, are visibly discontinuous within a given outcrop, we observed that these beds are commonly present at the same stratigraphic level in the next outcrop a few kilometers distant. From this, we concluded that, while beds or bed sets may be missing locally, they are commonly persistent over a broader area *as a series of lenses at the same stratigraphic level*. Further, many beds and bed sets show distinctive stacking patterns that can be identified in a succession of outcrops. Hence, the stacking pattern of limestone beds separated by shales of various thicknesses provide a "bar code" for recognition of particular stratigraphic intervals.

Table 1. Informal Terminology for Divisions and Beds of the Kope and Lower Fairview Fms.

| | |
|---|---|
| **FAIRVIEW FORMATION** | |
| FAIRMOUNT MEMBER (Upper Fairview) | |
| MT. HOPE MEMBER (Lower Fairview) | |
| Wesselman Submember | |
| "A. Miller shell bed" | |
| North Bend Submember | ~2.5 m; ="non-cyclic interval" |
| *Strophomena* beds | |
| **KOPE FORMATION** | |
| McMICKEN MEMBER (Upper Kope) | ~9-10 m; with basal Fairview, equiv. to |
| 1) Taylor Mill submember | Holland's C1-4 parasequence |
| a) upper Taylor Mill shale ("Two-Foot Shale") | |
| b) *Onniella* limestone (or "Z bed") | cycle 40 |
| c) *Diplocraterion* beds (or "Reidlin Road beds") | |
| d) Jennette's gutter cast bed | |
| e) "Y bed" | cycle 39 |
| f) "X bed" | cycle 38 |
| g) graded *Diplocraterion* beds ("W beds") | |
| h) basal Taylor Mill shale ("Big Shale #7") | ~2.5 m |
| 2) Grand Avenue submember | ~5 m; equiv. to upper part of Holland's C1-3 |
| a) upper Grand Avenue beds | cycle 37 parasequence |
| b) lower Grand Avenue beds | cycles 35-36 |
| c) basal Grand Avenue shale ("Big Shale #6") | ~1.5 m |
| SOUTHGATE MEMBER | |
| 1) Grand View submember | ~4.5 m; equiv. to lower part of Holland's C1-3 |
| a) "I-471 beds" | 4 regularly spaced beds; cycles 32-35 |
| b) "Grand View big bed" | cycle 31 |
| c) basal Grand View shale ("Big Shale #5", contains upper *Triarthrus* beds) | ~2 m |
| 2) Alexandria submember (or "red *Onniella* zone") | ~8 m; with Snag Creek sbmr., equiv. to |
| a) "Alexandria Pike twin beds" | cycles 29-30 Holland's C1-2 parasequence |
| b) "River Road triplet beds" | cycles 26-28 |
| c) "black *Onniella* beds" | cycle 25 |
| d) basal Alexandria shale ("Big Shale #4", contains Carrolltown gastropod beds) | ~2.5 m |
| 3) Snag Creek submember | ~7 m |
| a) "Snag Creek twin beds" | cycles 24a-24b |
| b) "Snag Creek triplet beds" | cycles 21-23 |
| c) lower Snag Creek shale ("Big Shale #3") | ~4 m |
| 4) Pioneer Valley submember (or "*Sowerbyella* zone") | ~17-18 m; named for Pioneer Valley Industrial |
| a) "upper White Castle bed" | cycle 20 Park, also known as "White |
| b) "middle White Castle bed" | cycle 18 Castle site" |
| c) Nigel Hughes' "trilobite beds" | cycle 16 |
| d) "lower White Castle bed" | cycle 15 |
| e) Newport Plaza hiatus concretion bed | cycles 12-14 |
| f) lower limestone beds | ~4 m; cycles 9-11 |
| g) basal shale/calcisiltite beds ("Big Shale #2") | |
| ECONOMY MEMBER | |
| 1) Brent Submember | ~14 m; equiv. to Holland's C1-1 parasequence |
| a) "3rd Brent twins" | cycles 7-8 |
| b) "2nd Brent twins" | cycles 6a-6b |
| c) "1st Brent twins" | cycles 5a-5b |
| d) lower Brent limestones | cycles 3-4 |
| e) basal Brent shale ("Big Shale #1") | ~4-5 m; cycles 1-2 |
| 2) Fulton Submember | |
| a) A through G limestone beds | |
| b) lower *Triarthrus* shales | |
| c) "*Glyptocystites fultonensis*" beds | |

# Figure 7. Correlated cross-section of Southgate Member, Kope Fm.

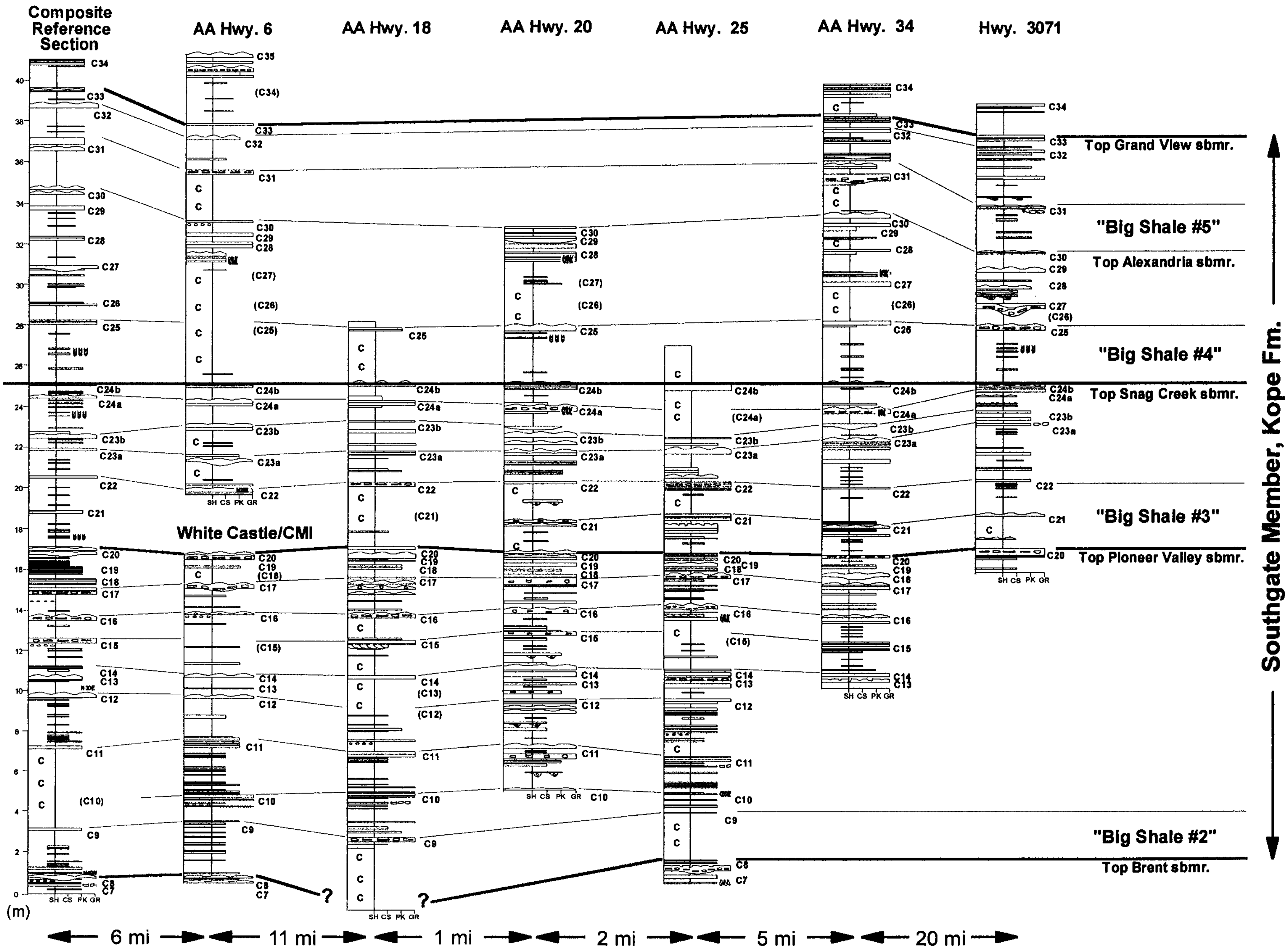
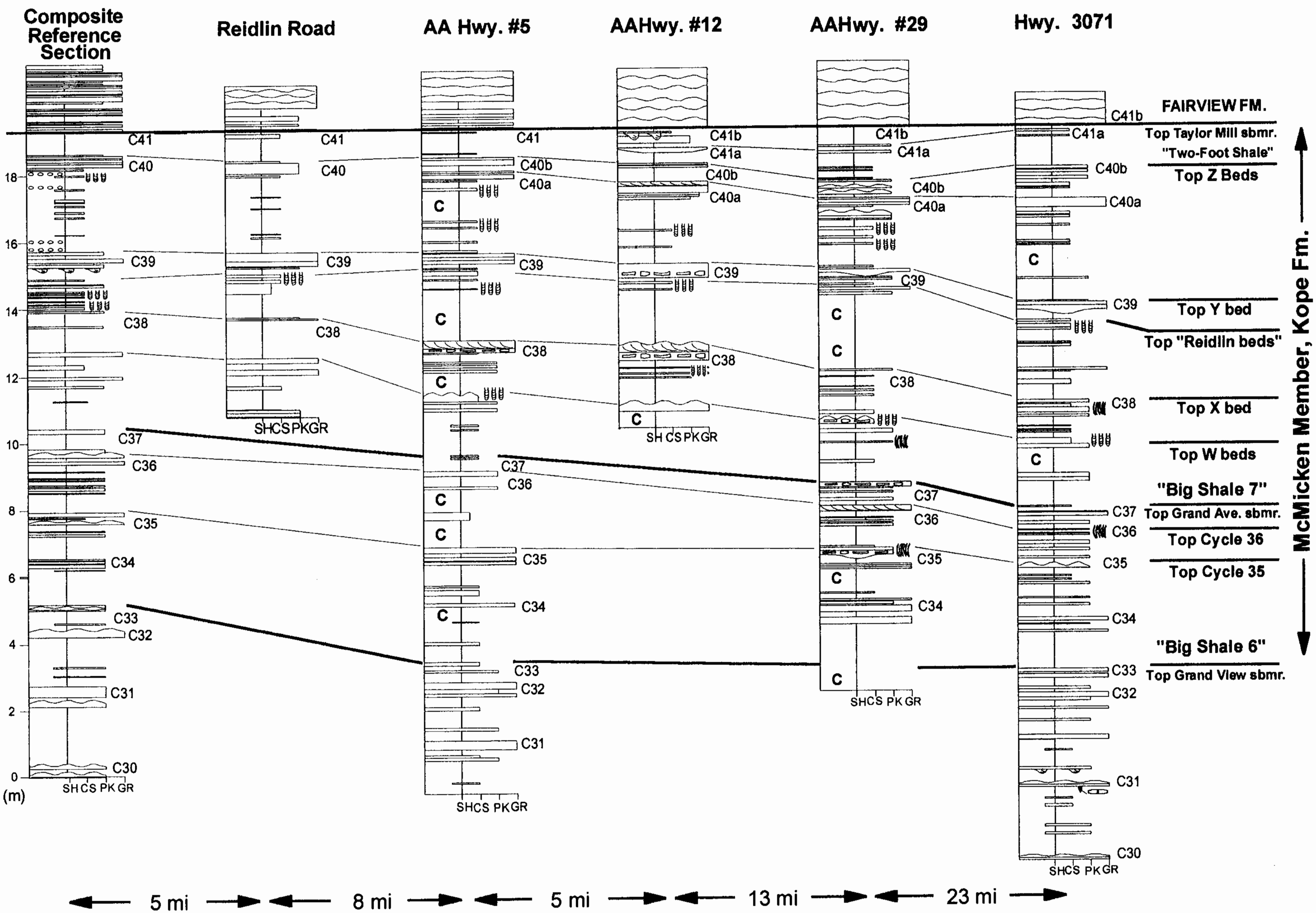


Figure 8. Correlated cross-section of McMicken Member, Kope Fm.



## STRATIGRAPHY OF EDENIAN TO LOWER MAYSVILLIAN STRATA OF THE CINCINNATI ARCH REGION

Although the classic Edenian and Maysvillian strata of the Cincinnati Arch region have been studied since the time of James Hall, many aspects of their detailed stratigraphy require further study on a regional basis. In the following sections, we provide a survey of the existing stratigraphic nomenclature of the Point Pleasant, Kope, and Fairview formations, and a discussion of proposed or modified stratigraphic units and subunits, particularly within the Kope Formation (Table 1).

### Point Pleasant Formation (or Point Pleasant Tongue of Clays Ferry Formation)

The oldest strata exposed in the area of Cincinnati are thin fossiliferous limestones of the upper Point Pleasant Formation (uppermost Shermanian or Mohawkian; Trenton or Lexington Group) at the top of the Middle Ordovician as typically defined (Figs. 12 and 19, p. 12, this volume). The strata are exposed at low elevations along the Ohio River and on the AA Highway in a small region around Brooksville, Kentucky, apparently as a result of development of a very gentle arch, the Moscow-Carntown Anticline (see Potter, 1996). The Point Pleasant beds are partially exposed along the banks of Duck and Holst creeks, where they comprise a series of thin-bedded, crinoid and brachiopod shell fragmental limestones with thin dark gray shale partings. A number of surfaces display well-defined megaripples oriented mostly at N35E to N45E. Irregular, darkly stained hardgrounds occur at several levels, and some of these are encrusted by holdfasts of crinoids, such as *Anomalocrinus* and *Lichenocrinus*. A one-meter thick zone of synsedimentary folding and minor faulting occurs about 7 m below the top of the Point Pleasant Fm. near Brooksville, Kentucky (see DeJong et al., this volume). A distinct angular discordance exists between these deformed beds and an overlying coarse crinoidal grainstone.

Biostratigraphic studies of the Point Pleasant Fm. indicate that it belongs to the *superbus* conodont Zone, suggesting a latest Shermanian Age (Sweet and Bergström, 1984). The Point Pleasant Fm. is overlain by Kope Formation shales that have yielded early Edenian graptolites (*Climacograptus spiniferus* Zone; Mitchell and Bergström, 1991). By general agreement, the base of the Kope Fm. near Cincinnati is the stratotype of the base of the Edenian Stage and, therefore, also marks the base of the Cincinnatian Series.

**Figures 7-8 (previous pages).** Detailed correlations of the Southgate Member of the Kope Fm. (Pioneer Valley, Snag Creek, Alexandria, and Grand View submembers (Fig. 7) and of the McMicken Member (Grand Avenue and Taylor Mill submembers) of the Kope Fm. (Fig. 8) between Cincinnati, Ohio, and Maysville, Kentucky.

### Kope Formation

The Kope Formation is a major package of shale-dominated strata between the limestone-dominated Point Pleasant and Fairview intervals (see CRS, Fig. 5). The Kope consists predominantly of soft, pale to medium gray, readily weathering mudstones or shales with very minor black or dark gray tongues, thin (generally one to five cm) beds of light gray laminated siltstone and/or calcisiltite, and thin to (rarely) medium (5 to 60 cm) beds of skeletal (brachiopod, bryozoan, and crinoid debris) packstones and grainstones. (e.g., Fig. 6). The latter typically form the caps of small bundles and may in some cases be abruptly overlain by mudstone. The mudstone itself varies from nearly barren to highly fossiliferous, locally containing intact colonies of branching bryozoans, articulated crinoids, trilobites, and other fossils (e.g., Fig. 4). Our measurements indicate that the Kope Formation is approximately 70-75 m (230-246 ft) in thickness in the Cincinnati region, which agrees well with measurements of Ulrich (1888) and Davis and Cuffey (1998).

The Kope Formation was named by Weiss and Sweet (1964) for exposures at Kope Hollow, at Levanna in southern Ohio, and the term was used in substitution for the biostratigraphically based Eden or Latonia

Formation (see Diekmeyer, 1998, for review). The Kope Formation coincides approximately with the Edenian local stage; the base of the Kope is generally placed at or near the base of the Edenian and, therefore, by most definitions also at the base of the Upper Ordovician Cincinnatian Series. The absolute age of the Edenian Stage has recently been estimated to be about 445.5 to 449.5 million years.

Bassler (1906) recognized three members in the "Eden Shales": (a) the lower Kope, or *Aspidopora newberryi* beds, was designated the Economy Member (originally reported as 28 m but subsequently as little as 16 m in thickness; Davis, 1994); (b) the middle Kope, typified by *Batostoma jamesi*, was assigned to the Southgate Member (ca. 36-37 m); and (c) the upper Kope, a limestone-rich interval with abundant *Dekayella ulrich,* was designated the McMicken Member (ca. 16-21 m; Table 1). These members were based in part upon unique bryozoan assemblages, but also partially on lithologic criteria. The term "Fulton beds" was introduced by Foerste (1905) for the basal dark shale tongues containing the trilobite *Triarthrus*, and, subsequently, the term Grand Avenue Member was introduced by Ford (1967) for a distinct 2.5- to 3-m-thick bundle of limestones and thinner shales about 10 m below the top of the Kope Fm. Weiss and Sweet also advocated abandoning the older member names because they felt that these were local, biostratigraphically based units and could not be traced laterally for any great distance beyond Cincinnati. However, because much of the older literature as well as some more recent reports (e.g., Davis, 1992) refer to Bassler's divisions, we have chosen to retain these names but to redefine them to aid in their recognition. We conclude that, as redefined, these divisions are traceable well beyond the Cincinnati area. In addition, we recognize a series of finer divisions within the Kope that are also widely traceable and that herein will be named as informal submembers, for purposes of detailed stratigraphic correlation (Table 1).

**Economy Member (Lower Kope):** The lower division of the Kope Shale, designated as the Economy Member by Bassler (1906), carries a distinctive fauna that includes the small eyeless trinucleid trilobite *Cryptolithus*, an abundance of the small brachiopod *Sowerbyella* and the bryozoan *Aspidopora* (especially in the upper part of this member). The thickness of the Economy Member has been variably reported as 16 to 28 m (Caster et al, 1961; Davis and Cuffey, 1998; Diekmeyer, 1998, based on Bassler, 1906). This discrepancy probably reflects both poor exposure of the lower Kope interval and confusion as to where to draw its upper boundary. Measurements by Holland et al. (1997) and the present authors suggest that a thickness of about 20-22 m is typical for the Economy Member in the Cincinnati region. This places the upper contact of the Economy Member at the base of "Big Shale #2" in our nomenclature (Fig. 5; Table 1) and at the top of Holland's sequence C1-1 (located at about 9 m in the Rte. 445 reference section; Fig. 5, p. 100, Holland et al., this volume); we also designate this level as the top of the Brent submember of the Kope Fm.

*Fulton submember:* Where observed, the upper contact of the Point Pleasant Formation with the Economy Member of the Kope Formation ranges from a lithologically abrupt transition from limestone to shale to a gradationally interbedded succession of beds (Fig. 12 and 19, p. 12, this volume). The basal Kope near Cincinnati has been referred to as the "Fulton beds" (Foerste, 1905); we consider the Fulton beds to be the first submember of the Economy Shale (Table 1). The Fulton interval contains an unusual fauna that Ulrich and Bassler (1914) considered to be a recurrence of the older Bromley Shale assemblage (below the Point Pleasant Fm.); it includes the inarticulate *Leptolobus*, a small form of *Leptaena*, and the crinoid *Merocrinus*. Many of the darker shales yield graptolites and the trilobite *Triarthrus*, which is normally restricted to dysoxic facies such as the Utica Shale of New York State. Such beds are intercalated with crinoidal grainstones and small carbonate concretions in the lower 2 m of the Kope Fm. at Duck Creek near the Rte. 445 reference section. The top of the Fulton submember is herein defined as the contact between a bundle of limestone beds about 4 above the base of the unit and an overlying ca. 6-m-thick shale (Big Shale #1) assigned to the Brent submember (see CRS; Fig. 5).

Near Brooksville, Kentucky, the contact between the upper Point Pleasant and Kope formations appears gradational and the basal beds lack the dark shaly tongues typical of the Fulton beds near Cincinnati. Here, the basal few meters of the Economy Member contain several unique faunal elements, notably the rhombiferan *"Glyptocystites" fultonensis* (presently being revised by C. Sumrall) and the large crinoid *Merocrinus*. At Holst Creek near Fosters, Kentucky, the lower 4.5 meters of the Kope Fm., representing the Fulton beds, include a suite of about five fairly regularly-spaced, 20-30 cm-thick limestone beds, primarily crinoid grainstones (Fig. 12, p. 12, this volume).

*Brent submember:* The Fulton beds are followed by a ca. 6- to 7-m-thick interval dominated by sparsely fossiliferous shale with thin (<5 cm), hummocky, laminated calcisiltites and minor packstones ("Big Shale #1"; see CRS, Fig. 5). This interval culminates in a series of three twinned packstone or grainstone beds with associated carbonate nodules or concretions, totaling about three meters in thickness; we term these the "Brent beds" for exposures along the Rte. 445 reference section at Brent, Kentucky (Fig. 23, p. 29, this volume). These fossil fragmental limestone beds are typically megarippled and weather a rusty color due to the presence of pyrite. They contain abundant fragments of *Sowerbyella*, *Onniella,* and slender ramose bryozoans as well as some sheetlike bryozoans and *Rafinesquina* (Fig. 6B). The top of this interval displays an abrupt shift back to shales and calcisilitites; faunal studies of Holland et al. (1999; this volume) also show a significant faunal shift above these beds (at about 9 m in the Rte. 445 reference section). Holland et al. used this shift to demarcate the top of Kope sequence C1-1. The base of their C1-1 sequence is not clearly defined, because the Rte. 445 reference section does not reach the lower Economy Member beds. The upper contact of sequence C1-1 is correlative with the boundary of the Economy and Southgate Members.

**Southgate Member (Middle Kope):** The middle portion of the Kope (approximately coinciding with the Southgate Member of earlier authors (e.g., Caster et al., 1955) is widely reported to comprise about 35 to 37 m of shale and thin siltstones/calcisiltites. It corresponds to all of Holland et al.'s (1997) C1-2 sequence and the lower 3/4 of their C1-3 sequence (the top of C1-3 being comprised of the Grand Avenue submember of the overlying McMicken Member of the Kope). The Southgate carries a somewhat less diverse fauna than the Economy but includes bivalve and gastropod assemblages, the trilobite *Flexicalymene granulosa*, and the bryozoan *Batostoma jamesi*. An important faunal change is the distinct shift from *Sowerbyella*-dominated assemblages to *Onniella*-dominated assemblages in the middle of the Southgate Member, at the contact between the Pioneer Valley and Snag Creek submembers (Fig. 5; Table 1). This faunal change coincides approximately with a graptolite zonal boundary, marked by a shift from abundant *Geniculograptus typicalis* (probably indicative of the *C. spiniferus* Zone) to *Geniculograptus pygmaeus*, indicative of the *G. pygmaeus* Zone (Figs. 3-4; Mitchell and Bergstrom, 1991).

The Southgate Member is divisible into four easily identifiable stratal packages herein assigned submember status (Fig. 7; Table 1). Each interval has a lower portion dominated by shale and an upper interval with numerous closely spaced thin limestone beds, including both calcisiltites and fossiliferous packstones/grainstones. We have termed these intervals the Pioneer Valley, Snag Creek, Alexandria, and Grand View submembers.

*Pioneer Valley submember:* This submember is equivalent to sequence C1-2 of Holland et al. (1997). The unit is named for good exposures near the Pioneer Valley Industrial Park, adjacent to KY Rte. 17 and about 0.5 mi. south of I-275 (called the "White Castle site" by Holland et al., 1997). It commences with a thick (ca. 11 m) sparsely fossilferous shale-calcisiltite interval ("Big Shale #2"; see CRS, Fig. 5). A rather poorly known bed that is rich in molluscs occurs near the base of this shale (S. Felton, pers. comm. 1999). At the Rte. 445 reference section, this 11-m interval contains only three limestone beds thicker than 10 cm; these beds are located at about 2.2 m, 6 m, and 10 m above the base of the unit. Each of these intervals shows a minor spike of thin ramose bryozoans, suggestive of minor shallowing and/or less turbid conditions. Near Carntown, the lower Pioneer Valley submember becomes much more carbonate rich, with up to half of this lower 11-m interval consisting of limestone beds (Fig. 9, p. 9, this volume).

A number of probable deeper water faunal elements make their first appearance in these shales; these include the delicate inadunate crinoids *Cincinnaticrinus* and *Iocrinus*. The crinoid *Ectenocrinus* is also abundant, sometimes occurring in dense masses or "log jams" of columns (Fig. 7, p. 69, this volume). The trilobite *Cryptolithus* is also relatively common in these beds. Two important horizons were recognized and traced in this interval: (a) a "worm bed" (rich in *Sphenothallus*) about 6.7 m above the base of the unit; and (b) a starfish bed, rich in *Taeniaster*, about a meter higher. The "worm bed" contains unique elements such as *Sphenothallus*, *Protoscolex*, and a bivalve fauna including *Rhytimya*.

The uppermost 3 m of the Pioneer Valley submember carries a distinctive suite of thick, megarippled beds (Fig. 3, p. 67, this volume) and shows an abrupt increase in ramose and cryptostome bryozoans ("Pioneer Valley beds"; see CRS, Fig. 5). These thick limestones are characterized by near-total dominance of the brachiopod *Sowerbyella* (Fig. 6A), which becomes uncommon above this level in the Cincinnati area. The three upper limestones form distinctive, thick, commonly limonite-stained ledges. The lowest is a megarippled crinoidal bed that contains reworked clasts encrusted by fossil bryozoans and crinoid holdfasts, probably deposited on a hiatal surface (Fig. 9, p. 70, this volume); it is informally called the "Newport Plaza bed" for occurrences behind a shopping plaza off Grand Avenue in Newport, Kentucky. This bed has been traced from near Batavia, Ohio, to near Big Bone Lick State Park, in Kentucky (M. Wilson, 1998; S. Felton, pers. comm. 1999). A shale bed containing well-preserved *Flexicalymene* and other trilobites occurs slightly above the hiatal concretion bed and was described recently by Hughes and Cooper (1999) from the Pioneer Valley ("White Castle") site. As yet this bed has not been traced to other outcrops. About 1.5 m above the Newport Plaza bed is a thick crinoidal grainstone ("White Castle bed") and a meter higher is the uppermost bed of the Pioneer Valley submember. This last bed is up to 30 cm thick and is an amalgamated crinoidal and *Sowerbyella* shell grainstone with large orange-buff mudstone clasts. It is distinctive in being the last major bed below a thick shaly interval at the base of the overlying submember.

*Snag Creek Submember:* The thick *Sowerbyella*-rich limestones of the Pioneer Valley submember are abruptly overlain by a shaly zone which culminates in distinctive orange-weathering siltstones and packstone beds (Fig. 7). The interval is about 8 to 8.5 m thick near Cincinnati. A siltstone about 0.5 m above the base is notable for exceptionally well-preserved trilobite traces; a second, higher siltstone bed is typified by millimeter ripples. These beds are well-exposed along the AA Highway just south-east of Snag Creek valley, for which they are named (Figs. 15-18, pp. 15-17, this volume).

The lower shale-rich interval ("Big Shale # 3") is characteristically rich in graptolites and passes upward into a distinctive series of closely spaced, bryozoan-rich limestone ledges that weather a rusty yellow. An interval rich in calcareous nodules, some containing oriented graptolites (Fig. 4), occurs about 1.5-2 m below the top of this package. The uppermost pair of limestones ledges (beds 24a and 24b), stands out especially well because it is overlain by a thick, relatively pure shale ("Big Shale #4") at the base of the overlying Alexandria submember (Fig. 16, p. 15, this volume). Below bed 24a at several localities are one or more lenticular beds consisting of coarse ramose bryozoan packstones and representing possible channel fills. Just west of the Snag Creek valley, a zone of ball-and-pillow deformation occurs about 2 m below the top of this submember (cycle 23; Fig. 16, p. 15, this volume). This deformed zone appears to be very local in extent.

*Alexandria Submember:* This distinctive interval is named for exposures along both sides of the AA Highway just west of East Alexandria Pike, near the town of Alexandria, Kentucky (Fig. 3, p. 5, this volume). Its base is a 2.5- to 3-m-thick, pure shale interval ("Big Shale #4") that is easily recognized in outcrops between Carrollton and Maysville, Kentucky. The base of this shale is notable in containing a horizon that is exceptionally rich in well-preserved uncrushed mollusc shells ("Carrollton gastropod bed"; Table 1). The fossil assemblage includes the gastropods *Lophospira*, *Sinuites*, *Ruedemania*, and *Cyrtolites*, the bivalves *Modiolopsis*, *Cycloconcha*, and *Lyrodesma*, and the nautiloids *Gomphoceas*, *Technoceras*, and *Cameroceras* (Ulrich and Bassler, 1914). Isolated specimens of an usually large, long-hinged morphotype of *Sowerbyella* as well as *Cryptolithus* also recur at this level. This fauna was noted by Ulrich as typical of the lower Southgate Member. The first appearance of the zonal graptolite *Geniculograptus pygmeaus* occurs at approximately this level (ca. 33 m above the base of the Rte. 445 reference section; Mitchell and Bergstrom, 1991).

The upper portion of the Alexandria submember shows a distinctive pattern of compact limestone ledges separated by intervals of rather pure shale (Fig. 7). The first ledge-forming limestone (bed 25) is typically tabular and contains blackened fragments of *Onniella* and other fossil debris ("black *Onniella* bed"). The overlying series of ledges (beds 26-30) are sharp-based 15- to 30-cm-thick buff-weathering packstones to grainstones containing shale clasts that are especially typified by a reddish discoloration of *Onniella* valves ("red *Onniella* beds"; Fig. 6B); this discoloration is possibly due to limonite impregnation. The upper two ledges (beds 29 and 30) are subequal in thickness and separated by about 60-70 cm of shale (n.b., these can be confused with beds 24a and 24b at the top of the Snag Creek submember). The upper bed is typically an amalgam of two limestones; the lower of which displays reworked encrusted concretions at several localities near Cincinnati.

*Grand View Submember:* This unit, named for exposures along the AA Highway near Grand View Road, is relatively thin (ca. 4.5-5 m) and includes a basal 1.3- to 2-m-thick pure dark gray shale ("Big Shale #5") that has been reported to contain a recurrence of the trilobite *Triarthrus*, otherwise known primarily from the basal Fulton beds. Holland et al. found *Cryptolithus* to be common immediately below this level. The base of this shale displays yet another bed rich in molluscs, especially the bivalves *Rhitimya*, *Cymatonota*, and *Psiloconcha*, typically preserved as molds; this bed also shows the recurrence of certain faunal elements found in the "Worm bed" of the lower Southgate Member. This thick shale is overlain sharply by a 40- to 60-cm-thick amalgamated bundle of packstone to grainstone beds, and that bundle, in turn, by three evenly spaced thick limestone ledges (Fig. 7). These beds also possess reddish weathering brachiopods, including both *Onniella* and *Rafinesquina*.

**McMicken Member (Upper Kope):** Approximately ¾ of the way through the thickness of the Kope Formation, a somewhat more compact bundle of limestone beds forms the previously named "Grand Avenue Member" (GAM) of the Kope Fm. It is composed of about 60-70% limestone beds and is more carbonate rich than the remainder of the Kope Fm. (Figs. 4-5, p. 6, this volume). It is overlain in turn by the shaly upper portion of the Kope, herein designated the "Taylor Mill submember" that finally grades upward into the Fairview Formation (Figs. 5 and 7, p. 6-7, this volume). Together, the Grand Avenue and overlying uppermost Kope were previously referred to as the McMicken Member. This interval has an approximate thickness of 15 to 16 m (Fig. 5; Bassler, 1906, Caster et al., 1951; Diekmeyer, 1998).

*Grand Avenue Submember:* This interval was named as a member by Ford (1967) for exposures along Grand Avenue just northwest of Bald Knob in Cincinnati. It is herein reclassified as a submember of the McMicken Member. As defined herein (and in nearly the original sense), the Grand Avenue submember begins with a relatively thick (90-100 cm) shale band ("Big Shale #6"; Fig. 8). This is overlain by an interval about 30 cm of closely spaced, thin packstone and grainstone beds, 45-50 cm of shale with thin lenses of limestone, and then the main body of "Grand Avenue beds," about 2.5 to 3 m composed of numerous closely spaced, thin and laterally discontinuous packstones and fossiliferous shales, resembling the upper Fairview Formation. In most outcrops, this interval is divisible into two or three bundles of limestone beds by somewhat more shaly zones. A highest compact limestone (bed 37) occurs about 0.5 m above the main mass of Grand Avenue beds but is included in the Grand Avenue submember. The Grand Avenue is very rich in bryozoans, especially *Dekayella* and *Batostoma* and contains abundant *Rafinesquina*, sometimes as edgewise coquinas. In outcrops near Maysville, the unit has yielded *Constellaria*, a bryozoan generally associated with the Fairview Formation.

*Taylor Mill submember:* The highest division of the Kope Fm. is very distinct from both the Grand Avenue beds and the overlying Fairview Formation; together with the North Bend submember of the overlying Fairview Formation, it corresponds to the C1-4 sequence of Holland et al. (1997). This interval is generally 9.5 to 10 m thick and contains a very distinct succession of beds (Fig. 8). It is excellently exposed along Taylor Mill Road at its junction with Mason/Reidlin Road, where it has been well studied by Diekmeyer (1998), Jennette and Pryor (1993), and others. It is much more shaly than the Grand Avenue submember and commences with a pure shale ("Big Shale #7") about 1.5 m thick. Above this interval at most localities is a distinctive two-part graded bed with a packstone base overlain by thick hummocky-laminated calcisiltite with large *Diplocraterion* burrows ("W beds"). A second calcisiltite-packstone bundle occurs about 2 m higher ("X bed"). These beds are rich in bryozoans and *Onniella* and are separated by thick shales containing numerous burrowed calcisiltites.

Toward the top of the interval, several beds form outstanding markers. A 50-cm-thick limestone bundle ("Y-bed") has at its base a prominent 10-15 cm siltstone bed with distinctive *Diplocraterion* and penetrative millimeter ripples ("Reidlin Road bed") and a gutter cast bed; both have been found in many localities around Cincinnati (Fig. 8; Jennette and Pryor, 1993). This is overlain by about 2.5 m of shale containing numerous calcisiltites. At the top of the Taylor Mill submember is a distinctive compact bundle (up to six beds) of *Onniella*-rich packstone and grainstone ("*Dalmanella* bed" of older literature), followed by a final 60- to 80-cm-thick shale interval (the so-called "Two-Foot Shale bed"), and then densely stacked grainstones of the basal Fairview. All of these beds are laterally persistent and have been observed in virtually all outcrops of the uppermost Kope (Fig. 8).

**Fairview Formation**

The Fairview Formation ranges from about 28 to 32 meters thick, thickening slightly from Maysville to the Cincinnati area, and consists predominantly of limestones. The interval is locally subdivisible into bundles of limestone and thinner intervals of shale. In contrast to the Kope Fm., limestone predominates in most intervals of the Fairview (averaging about 60% of total thickness), at least in the Cincinnati to Maysville area. Tongues of more shaly material have been detected to the north in Ohio. The most prominent of these is a shaly wedge (the Wesselman tongue of the "Kope Formation") that separates compact limestones of the lower third of the Fairview (North Bend tongue) from compact limestones of the upper third of the Fairview in northern Hamilton, Butler, and Adams counties (Schumacher, 1998). The lower compact ("non-cyclic") interval contains a distinct epibole of the brachiopod *Strophomena planumbona*. This compact limestone interval is an important marker bed in outcrop and in the subsurface (Schumacher, 1992). Minor thin shale shaly tongues are also recognized in the Alexandria to Maysville exposures of the Fairview Formation. The Fairview constitutes the lower part, or approximately 2/3 of the thickness, of the type Maysvillian Stage. The Fairview Fm. is dominated by shell-rich beds composed primarily of the brachiopod *Rafinesquina*. Diverse other brachiopods, including *Platystrophia laticosta* (s.l.), *Hebertella*, *Zygospira modesta,* are common at many levels. Certain beds within the Fairview Fm. display sharply burrowed tops and may represent firmgrounds or hardgrounds. Also, the upper Fairview contains distinctive horizons of strongly deformed limestone that have been interpreted as seismites.

## IMPLICATIONS OF DETAILED CORRELATION OF THE KOPE FORMATION

We have attempted detailed correlations for two intervals of the Kope Formation: (1) the Southgate Member, the 35- to 40-m-thick middle third of the Kope (Fig. 7), and (2) the McMicken Member, the 15-m-thick upper third of the Kope, immediately below the well-defined contact with the overlying Fairview Formation, (Fig. 8). These intervals were chosen because they are easily recognizable and identifiable based on criteria independent of the lithology of the strata. Our correlations provide unequivocal evidence for the persistence of certain distinctive decimeter- to meter-scale limestone beds and bed bundles as well as certain shaly intervals throughout the Cincinnati-Maysville region. In some cases, even single event beds such as distinctive calcisiltite with gutter casts or with other types of sedimentologic features can be traced over this distance.

Comparison of the Kope Fm. near Cincinnati (Rte. 445 reference section) with the Rte. 3071 roadcut in Maysville shows that all submembers in the upper 40 m of the formation are easily discernible across this distance of ca. 80 km (n.b., the lower 30 meters of the Kope is not exposed at Maysville). This strong correlatability reflects the persistence of the "Big Shale" intervals, as well as the major bundles of limestones separating them (Figs. 7-8). The thicknesses of both of these major components show only minor changes over this distance, being slightly thicker at Maysville. Moreover, facies in the Kope Fm. in both areas are quite similar. Relative to the Cincinnati area, the Kope Fm. at Maysville exhibits somewhat thicker limestone bundles, and calcisiltites that are both thicker and somewhat more numerous.

In contrast to the apparent uniformity of facies and unit thicknesses along the Cincinnati-to-Maysville transect, much more significant facies and thickness changes are apparent over comparable distances along transects in other directions (e.g., southward along I-75 toward Lexington, Kentucky). This strongly suggests that the Cincinnati-Maysville transect exposed along the AA Highway is closer to being parallel to depositional strike than normal to it. The slight changes in lithofacies and biofacies of the Kope Fm. observed along this transect suggest that the Maysville area represents a slightly more proximal facies than the Cincinnati area. Evidence for shallower ramp conditions in moving southeastward from the Cincinnati area is even stronger in the overlying Fairview and Grant Lake formations (see Schumacher, 1992). In any case, our observations suggest that local depositional strike is closely coincident with the NW-directed, Maysville-to-Cincinnati segment of the Ohio River (and thus also parallel to the AA Highway). This provides empirical support for Ettensohn's (1999; in review) reconstruction of a NW-SE-oriented embayment in the Sebree Trough just north of the Greater Cincinnati area.

A further implication of this work is that the processes responsible for producing the pattern of thicker shales and limestone bundles (putative cycles) and even individual thicker beds were pervasive over wide tracts of the ramp, at least parallel to and, to a limited extent, across depositional strike. At least in this portion of the Cincinnatian Series, the empirical evidence suggests a stratigraphic pattern closer to a layer cake than the local facies mosaic that has been depicted in recent stratigraphic charts (e.g., Fig. 1; Cuffey, 1998). This result strongly supports the inference that these stratigraphic patterns were generated by allocyclic processes (e.g., eustatic sea level or climatic changes) as opposed to strictly local autogenic phenomena.

One significant departure from lateral facies uniformity is observed along the AA Highway. The Pioneer Valley submember appears distinctly more limestone rich and coarser grained in the region around Carntown to Brooksville, mid-way between Cincinnati and Maysville. Also, Upper Kope limestone beds are slightly thicker and more prominent in this area. This may reflect the existence of a gentle paleo-swell in this area, resulting in slightly shallower water depths there than to either the north or south. It is intriguing that this is also the area of the gentle "Moscow-Carntown anticline" recognized by Potter (1996). These are preliminary observations but they suggest the need for additional study.

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