High-Resolution Correlation in Apparently Monotonous Rocks: Upper Ordovician Kope Formation, Cincinnati Arch

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Short stratigraphic sections in apparently monotonous strata pose several challenges to high-resolution (<1 m) correlation. A lack of distinctive marker horizons can prevent obvious visual correlations between the sections. The stratigraphic shortness of the outcrops further reduces the likelihood of any given section having a recognizable marker horizon. The Upper Ordovician Kope Formation of the Cincinnati, Ohio, area exhibits both of these problems and correlation within the Kope has not been accomplished easily, to date. However, cross-correlation of meter-scale cycles in the Kope can be used to identify potential correlations of small outcrops to larger, well-described outcrops. If multiple correlations are equally plausible, large-scale faunal transitions among facies fossils can then be used to select the best correlation. In this pilot study, two sections separated by 9 km are correlated successfully using these methodologies, which show promise for the correlation of numerous outcrops in the Cincinnati area. In addition, the methods described here may be applied easily to other areas of limited outcrop in which the rocks are so complexly cyclic that they, likewise, appear to be monotonous.

INTRODUCTION

Stratigraphic correlation is one of the most basic of all geologic problems, yet it is frequently one of the least straightforward to solve. All correlation is ultimately based on pattern matching of features thought to be temporally significant. Such features might include overall faunal or lithologic similarity of intervals of strata, or distinctive surfaces such as an ash bed, a sequence boundary, or the first occurrence of a species. In common practice, most correlation is a qualitative exercise lacking a quantifiable measure of the robustness or validity of the correlation. As a result, comparing correlations achieved by different methods is not straightforward and can involve a large degree of personal preference for particular methods. Although several numerical methods of correlation have been developed (Gradstein et al., 1985; Mann and Lane, 1995), in general they have not been widely adopted, with the possible exception of graphic correlation.

An additional problem arises when correlating stratigraphically short, isolated outcrops in areas of limited exposure to longer, well-described outcrops. Longer sections are relatively easier to correlate to one another because it is more likely that they will both contain one or more distinctive horizons that can be matched. In rocks that are lithologically or paleontologically monotonous, the precise position of short stratigraphic sections within the overall stratigraphic framework is commonly ambiguous.

The Upper Ordovician Kope Formation of the Cincinnati, Ohio, area possesses both of these problems. The 60- to 70-m-thick Kope Formation consists of varying proportions of shale and interbedded limestone. The formation is complexly cyclic, which has hampered previous efforts to recognize patterns of lithologic change. As a result, nearly every worker who has studied the Kope Formation has described it as monotonous. Although long exposures of the Kope can be found, particularly along interstate highways, far more common are the much shorter exposures along small roads, streams, and railroads. A variety of methods have been used to correlate these sections, including elevation, marker beds, fossil content, and stratigraphic cycles, but the results are commonly imprecise (>1 m uncertainty).

The discovery of a cluster of articulated trilobites (Hughes and Cooper, 1999) motivated us to devise a method for correlating these smaller outcrops with a high degree of precision into our developing stratigraphic framework for the Kope (Holland et al., 1997). Similar occurrences of well-preserved trilobites and echinoderms are not unusual in the Kope, yet the inability to correlate has hampered the recognition of patterns in the stratigraphic distribution of beds containing unusually well preserved fossils. Because these problems in correlation are not unique to the Kope, the techniques we describe here could apply to other regions of limited exposure and relatively monotonous successions.

REGIONAL BACKGROUND

The Kope Formation is exposed throughout northern Kentucky, southwest Ohio, and southeast Indiana. It was deposited over an estimated span of 2–3 million years and comprises most of the C1 depositional sequence of Holland and Patzkowsky (1996) in the Cincinnati area (Fig. 1). The Kope was deposited in an offshore environment on a northward-dipping storm-dominated ramp (Tobin and Pryor, 1981; Jennette and Pryor, 1993). Shale comprises roughly two-thirds of the Kope, with the remainder consisting of very thin to medium beds of calcisiltite, skeletal packstone, and skeletal grainstone, all deposited as storm beds.

The Kope exhibits cyclicity at a range of scales (Jennette and Pryor, 1993; Holland et al., 1997). Meter-scale cycles are the smallest of these units and consist of alternating shale-rich intervals and intervals dominated by skeletal packstones and grainstones (Fig. 2). Shale-rich intervals are interpreted as distal storm-bed facies, whereas intervals rich in skeletal packstones and grainstones are interpreted as proximal storm-bed facies (Jennette and Pryor, 1993). Meter-scale cycles show vertical trends in thickness that define larger-scale cycles roughly 20 m thick (Fig. 3). Meter-scale cycles are thicker than average in the lower parts of 20-m cycles and are average to thinner than average near the top. Successive 20-m cycles display an aggradational to slightly progradational stacking pattern, characterized by an upward increase in the proportion of

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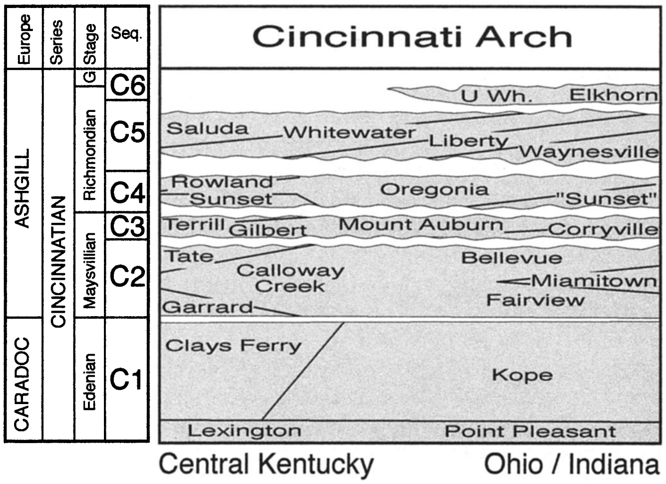

FIGURE 1—Stratigraphy of the Upper Ordovician on the Cincinnati Arch. Study interval spans most of the Kope Formation and the basal portion of the Fairview Formation near Cincinnati. C1 through C6 sequences refer to third-order depositional sequences recognized by Holland and Patzkowsky (1996) on the Cincinnati Arch, Nashville Dome, and Valley and Ridge of Tennessee and Virginia.

limestone, which is interpreted to indicate overall upward shallowing within the Kope. The presence of multiple scales of cyclicity has hampered the previous recognition of correlatable lithologic changes. Furthermore, because the limestone-to-shale ratio tends to increase depositionally updip, lithologic changes found in any one area are difficult to follow elsewhere, adding to the sense that vertical lithologic changes are not easily correlated.

The study we present here involves the correlation of two outcrops in the Kope of northern Kentucky (Fig. 4). The White Castle section contains the unusual bed of well-preserved trilobites (Hughes and Cooper, 1999). We correlate this section to a much longer section through the Kope at the K445 composite outcrop (Holland et al., 1997). The K445 section is nearly complete, and ranges from several meters above the basal Kope—Point Pleasant contact to several meters above the contact of the Kope with the overlying Fairview Formation. The White Castle and K445 sections are separated by 9 km.

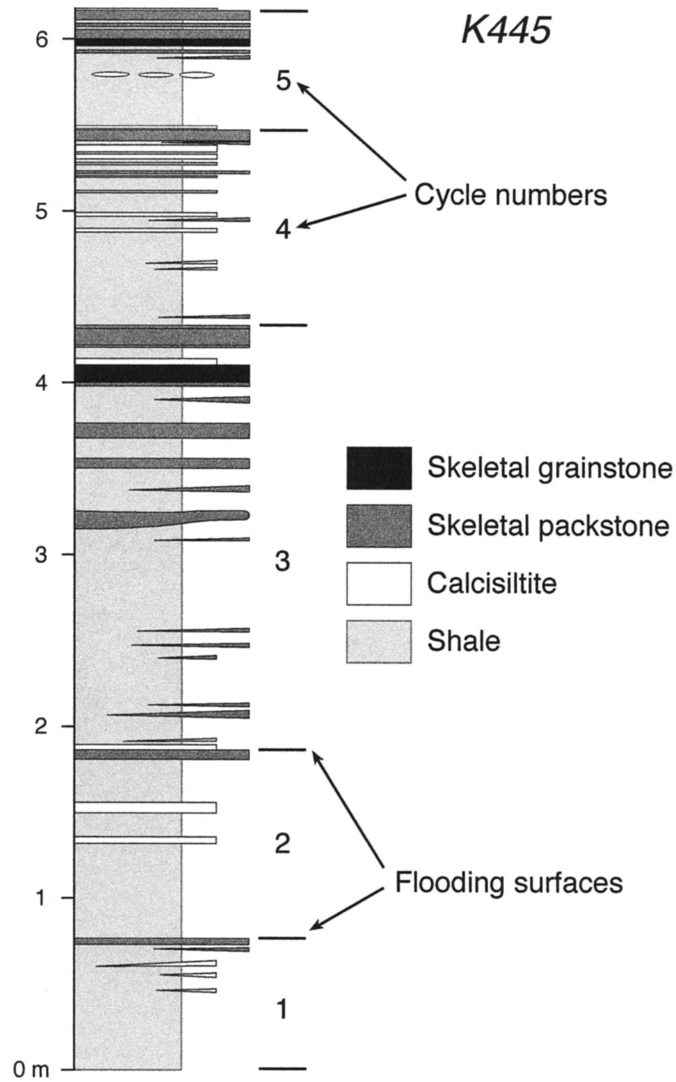

FIGURE 2—Typical meter-scale cycles of the Kope Formation. Section shown is a portion of the K445 composite outcrop; complete section is in Holland et al. (1997). Meter-scale cycles consist of a lower shale-rich unit and an upper unit of skeletal packstones and grainstones. For consistency among all cycles, cycle boundaries are placed at flooding surfaces, although some cycles have the structure of sequences (complete with small-scale sequence boundaries and systems tracts) rather than parasequences. See Holland et al. (1997) for a more complete discussion of the anatomy of these meter-scale cycles.

ALTERNATE METHODS OF CORRELATION IN THE KOPE

A variety of strategies have been used to correlate within the Kope. Rocks in the Cincinnati area dip gently, usually less than 0.5°, allowing elevation to be used for local correlations. However, even these gentle dips can lead to uncertainties of 5–10 m over distances of a kilometer. As a result, elevation is useful only as an approximate means of correlation.

The abundant macrofossils—brachiopods, bryozoans, trilobites, crinoids, and molluscs—have also been used for correlation in the Kope. Most of these have local ranges that are strongly controlled by subtle facies changes, and the abundances of many genera change systematically within the Kope (Fig. 5). For example, the crinoids *Cincinnaticrinus* and *Iocrinus,* as well as the thin disc-shaped bryozoan *Aspidopora,* tend to occur most commonly near the bases of the 20-m cycles, particularly low within the Kope. These positions are interpreted as relatively deeper-water offshore facies based on storm bed proximality, cycle anatomy, and overall cycle-stacking patterns (Jennette and Pryor, 1993; Holland et al., 1997). Robust bryozoans and the brachiopods *Strophomena, Platystrophia,* and *Rafinesquina* occur most commonly near the tops of 20-m cycles and especially near the Kope-Fairview contact. These positions are interpreted as being shallower water, although still deposited within an offshore environment. These relatively shallower and deeper offshore facies in the Kope differ by subtle differences in their limestone-shale ratio that are easily overlooked. Because these taxa are facies controlled, their local ranges within the Kope

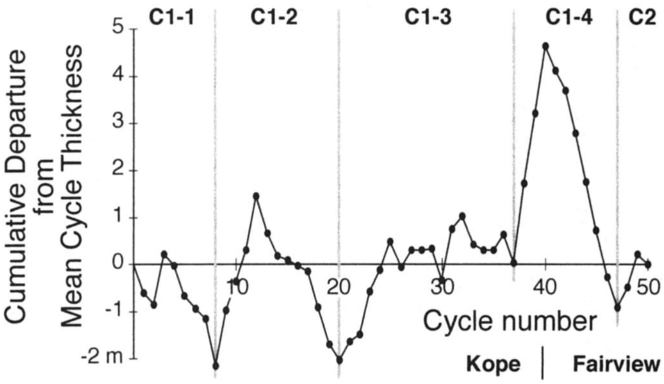

FIGURE 3—Fischer plot of meter-scale cycles at the K445 section, displaying systematic thickening and thinning trends. Note that Fischer plot displays only trends in cycle thickness; triangles showing thicknesses of individual cycles are not shown. Several 20-m cycles are visible (labeled C1-1, C1-2, etc.). Each 20-m cycle is characterized by an initial series of thicker than average meter-scale cycles followed by several average to thinner than average meter-scale cycles. Successive thickening of cycles is interpreted as upward-deepening and successive thinning of cycles is interpreted as upward-shallowing.

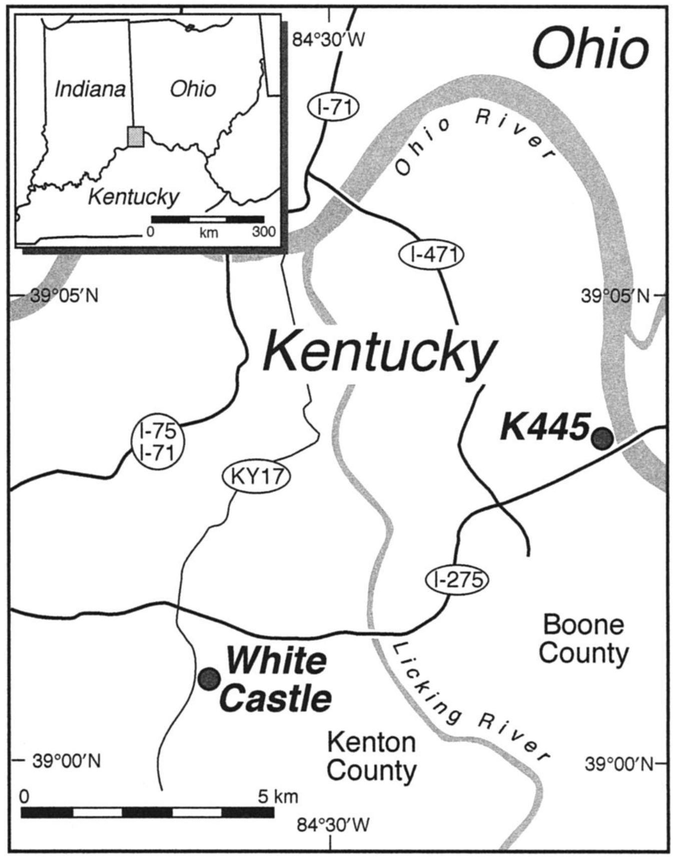

FIGURE 4—Location of K445 and White Castle outcrops. See appendix for detailed locality descriptions.

change in outcrops depositionally updip and downdip. Shallow-water species tend to have shorter, more fragmented stratigraphic local ranges in downdip sections and longer, more continuous local ranges in updip sections. The opposite pattern is true for deep-water species. Thus, correlation purely with fossils is likely to lead to imprecise correlation particularly if followed for more than a few kilometers.

Graptolites and conodonts also have been used for correlation in the Kope. Although graptolites are common and diverse (Bergström and Mitchell, 1991; Mitchell and Bergström, 1991), the single zonal boundary recognized within the Kope is insufficient for establishing the numerous lines of correlation needed to correlate small outcrops with precision. Conodonts have been used primarily in graphic correlation and have been effective in correlating much of the Middle and Upper Ordovician of North America (Sweet, 1979; Sweet, 1984). However, the inherent 6-m precision of this graphic correlation is too coarse for high-resolution correlation within the Kope.

Some of the more distinctive storm beds within the Kope have permitted correlation in limited instances. For example, a single bed of gutter casts has been correlated for 43 km, largely along depositional strike (Jennette and Pryor, 1993). Similarly, a bed containing abundant *Diplocraterion,* or U-tube trace fossils, has been correlated for over 10 km, also mostly along depositional strike (Tobin, 1982). However, such beds are not unique. Gutter casts occur at a number of stratigraphic levels and *Diplocraterion* occurs sporadically throughout the Kope. Correlations using these beds work only if the sections already have been approximately correlated by other means.

Meter-scale cycles also have been used for regional correlation (Jennette and Pryor, 1993). Most of these cycles look more or less like any other; hence, it is only where distinctive features occur, such as abrupt changes in cycle thickness, or where distinctive successions of cycles occur that cycles can be matched. In the past, this has been possible only near the top and the bottom of the Kope Formation where the limestone to shale ratio and the thickness of meter-scale cycles changes abruptly. Once a distinctive contact has been matched, cycles are simply correlated one to another progressively away from the marker horizon. Without such a distinctive marker, cycles have been correlated only through qualitative visual matching. Because Zeller's (1964) classical experiment in correlation showed how faith in correlation could drive workers to find correlations even in randomly generated stratigraphic sections, a more quantitative, repeatable, and objective method of correlation is preferred.

CROSS-CORRELATION

To avoid the problems associated with these alternative methods, we used the technique of cross-correlation to correlate meter-scale cycles (cf. Anderson and Kirkland, 1966; Dean and Anderson, 1974). As a first step, meter-scale cycles were identified in both sections. Next, the two sections were lined up cycle-for-cycle, with the first cycle in the one section correlated to the first in the second section, the second cycle with the second cycle, and so on. The thicknesses of pairs of cycles were compared and Pearson's correlation coefficient (r) of cycle thicknesses in the two sections was calculated. One section was then shifted by one cycle relative to the other and the process was repeated. This continued until a correlation coefficient was calculated for each possible value of cycle offset.

Because the distinctive upper or lower contacts of the

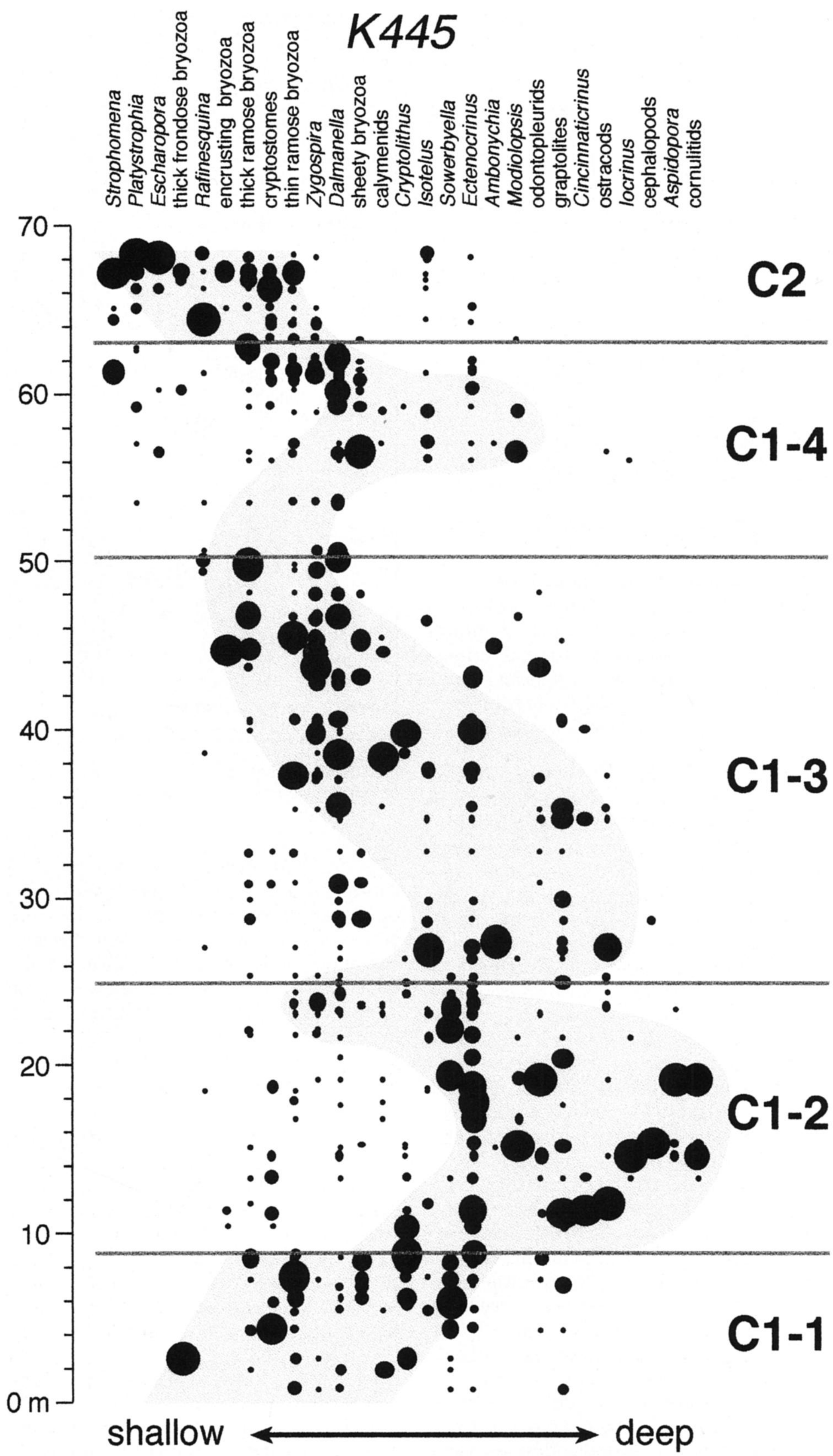

FIGURE 5—Distribution of common macrofossils in the K445 section. Diameter of circle indicates relative abundance; gray shading highlights stratigraphic trends in faunal composition and abundance. Taxa are ordered by seriation from left to right in terms of their apparent depth preferences. Data are from bed-by-bed faunal censuses collected as part of our ongoing stratigraphic analyses of the Kope. Lower half of C1-1 20-m cycle is missing at this locality.

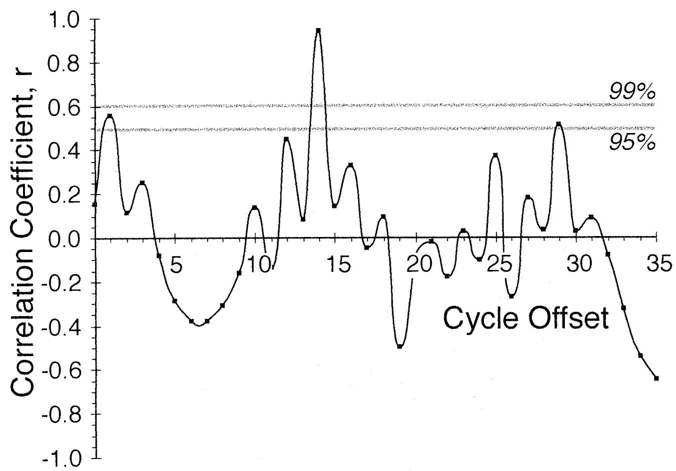

FIGURE 6—Results of cross-correlation between K445 and White Castle meter-scale cycles. 95% and 99% confidence values are calculated from randomization of the two sections and are based on one million iterations. Multiple scales of cyclicity are apparent in the results, including a cycle of 2 meter-scale cycles and one of 13-to-15-meter-scale cycles. These cycles in the cross-correlation coefficient represent systematic trends in thickening and thinning of meter-scale cycles; the cycle of 13–15 corresponds to the 20-m cycles previously described. Offsets of 1, 14, and 29 indicate statistically significant correlations of the two sections.

Kope are not present in the shorter White Castle section, we know that it must lie entirely within the interval of the longer K445 section. Thus, we need to consider only those correlations that place the White Castle section entirely within the longer K445 section. Therefore, the value of zero cycle-offset represents the correlation when the lowermost meter-scale cycles in the two sections are matched up. The maximum value of cycle offset (35) represents the correlation when the uppermost meter-scale cycles in the two outcrops are paired (Fig. 6). The maximum value of cycle offset is the difference in the number of cycles in the two outcrops, and represents one less than the number of possible correlations of the two sections.

Cross-correlation of the meter-scale cycles in the two sections produces a number of patterns. Cross-correlation values show a strong periodicity of two cycles, reflecting a strong trend for successive cycles to alternate in their thickness. Alignment of the thicker cycles of these pairs in both sections generates high positive values of r, whereas alignment of the thin cycles of one section with the thick cycles of the other leads to high negative values of r. A longer cycle in values of offset is also apparent, defined by the peaks at cycle offset values of 1, 14, and 29 and the intervening troughs. The systematic thickening and thinning of meter-scale cycles within 20-m cycles drive this longer cycle in cross-correlation. This pattern of thickening and thinning is so similar in successive 20-m cycles that three different correlations of the White Castle section to the K445 section are equally plausible. Although a cycle offset of 14 generates the maximum observed value of r (0.94), the values of r at offsets of 1 (0.55) and 29 (0.51) are also statistically significant at 95% confidence.

Each of the 20-m cycles at K445 consists of relatively thin meter-scale cycles at its base and relatively thick cycles near its top (Fig. 3). In the White Castle section, the lowermost meter-scale cycles are relatively thin and the uppermost meter-scale cycles are thicker (Fig. 7), indicating that the White Castle section must include one of the 20-m cycle boundaries. Thus, the White Castle section spans the C1-1/C1-2 boundary, the C1-2/C1-3 boundary, or the C1-3/C1-4 boundary. Clearly, only one correlation can exist between the two sections, but cross-correlation alone is insufficient in this case to find it unambiguously.

FAUNAL CORRELATIONS

The distribution of macrofossils within the two sections can be used to choose the best of these three potential correlations. Even though the most abundant fossils in these sections are facies fossils and their local ranges may change by several meters over just a few kilometers laterally, these changes do not prevent discrimination among these three correlations.

Most of the taxa in the White Castle section have relatively long local ranges and are not helpful for correlation (Fig. 7). However, some fossil distributions are more limited and, thus, more helpful. For example, the brachiopod *Sowerbyella* is abundant low in the White Castle section, but disappears abruptly for the remainder of the section. In addition, pieces of the trilobite *Cryptolithus* and the brachiopod *Rafinesquina* are absent in most of the section, but appear as float high in the section, indicating that they occur in overlying strata.

The distribution of these genera can be compared to their distribution in the K445 section (Fig. 5) to achieve a final correlation. The C1-1/C1-2 boundary at K445 has abundant *Sowerbyella* like the White Castle section, but it also has abundant *Cryptolithus,* which is absent at that level at White Castle. The C1-2/C1-3 boundary also has abundant *Sowerbyella* and lacks common *Cryptolithus* or *Rafinesquina,* so it is similar to White Castle. The C1-3/C1-4 boundary lacks both *Sowerbyella* and *Cryptolithus* and contains common *Rafinesquina,* so it is highly dissimilar to White Castle.

These faunal patterns confirm that the middle of the three cross-correlation peaks should be selected; that is, the one that corresponds to the C1-1/C1-2 interval. In this way, the two sections can be quantitatively correlated with a high degree of precision (Fig. 8). In contrast to traditional pattern-matching methods, a level of confidence (>99%) also can be assigned to this correlation, indicating that the successions of cycle thicknesses in these sections are too similar for this correlation to have arisen by chance. The occurrence of the trilobite lens reported by Hughes and Cooper (1999) can be located within our thicker K445 outcrop to a precision of half a meter within the 60-m thick section. Such correlations of other unusual fossil occurrences in the Kope Formation ultimately may lead to a better understanding of large-scale patterns of beds of unusual preservation and their possible sequence stratigraphic context.

DISCUSSION

Cross-correlation was used widely in the 1960s and 1970s in early attempts to automate stratigraphic correlation. Its initial successes came with varve correlation, where the thicknesses of successive varves were used to correlate over distances of several hundred kilometers

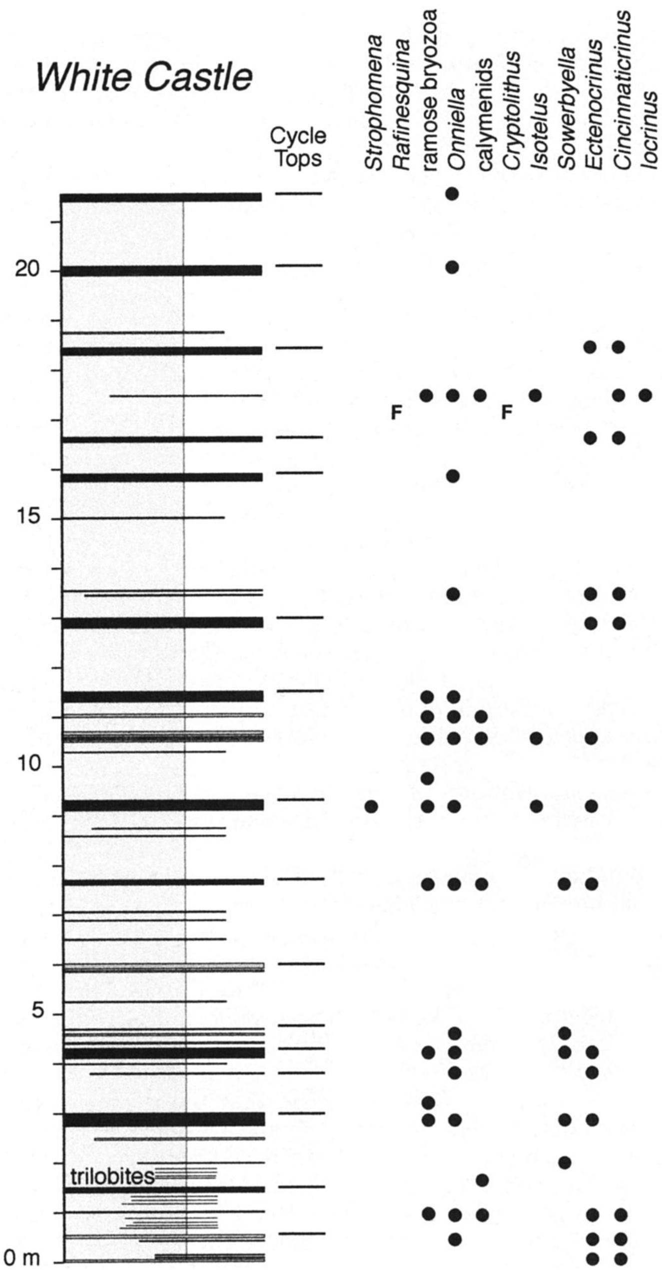

FIGURE 7—Presence/absence of common macrofossils in the White Castle section. All occurrences are from *in situ* ledges of limestone, except for "F", which were found in float and are shown here because they indicate the presence of these forms upsection. The trilobite lens reported by Hughes and Cooper (1999) is located just below meter 2. The apparently lower diversity in the White Castle section relative to the K445 section reflects the greater sampling intensity at K445.

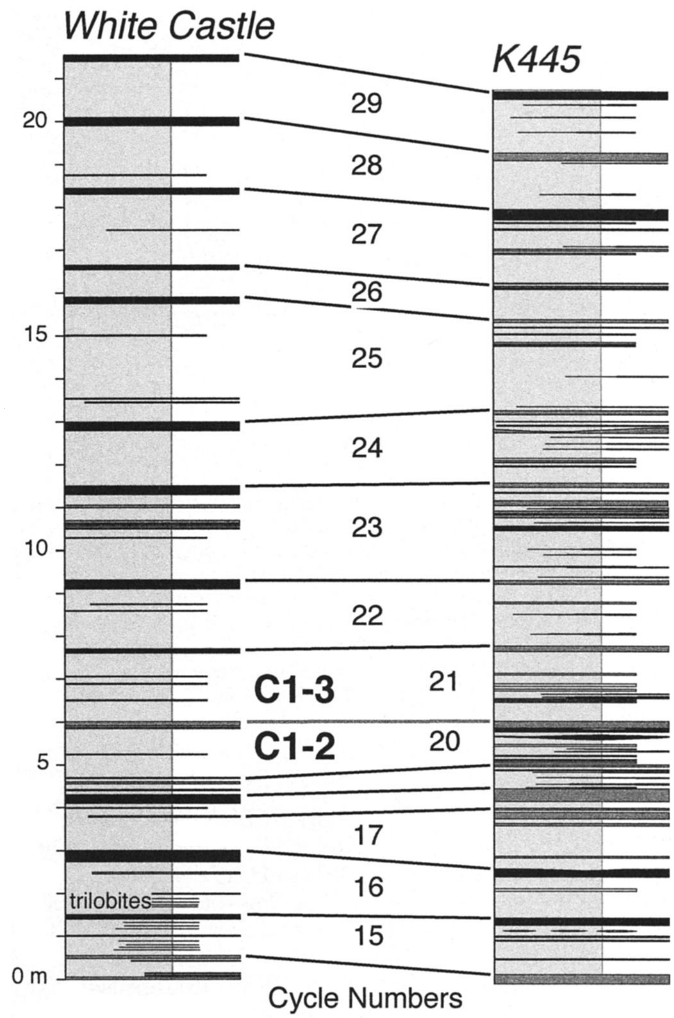

FIGURE 8—Final correlation of White Castle and K445 sections. Occurrence of trilobite lens at the White Castle section is equivalent to meter-scale cycle 16 of the K445 section. White Castle section spans the C1-1/C1-2 20-m cycle boundary. The fewer number of limestone beds at White Castle reflects the less intensive measurement of this section relative to K445.

(Anderson and Kirkland, 1966). It also was successfully applied to the correlation of turbidite successions, again based on the thicknesses of successive beds (Dean and Anderson, 1967). Both of these studies used the Sliding Correlation Coefficient (Dean and Anderson, 1974), in which bed or laminae thickness is the dependent variable and bed or lamina number is the independent variable. The thicknesses of the varves or beds in the two sections progressively are correlated to one another for different values of offset. The peak value in correlation is the statistical best match between the two sections. Provided the sections lack significant gaps, this approach is readily capable of finding correlations. Furthermore, the complications caused by stratigraphic gaps can be avoided by correlating short sections or short portions of one section with another much longer section. In this way, it is unlikely that the short section, if chosen correctly, will span a gap and lead to an erroneous correlation. Spuriously high correlations can result, however, from random variations in bed or varve thickness, from cyclic variations in thickness, or from net trends in thickness. Other geologic evidence must be used to eliminate these spurious correlations.

Cross-correlation techniques were later extended to other types of data, particularly electric log data collected from wells. Some property, such as resistivity or gamma response (the dependent variable) was measured as a function of depth in the well (the independent variable). By using a Moving Correlation Coefficient (Dean and Anderson, 1974) the dependent variables of both sections are correlated, and the sections are progressively offset by some constant value of rock thickness. This is repeated for all possible values of offset, and the offset with the highest correlation coefficient is considered the best statistical match between the sections. This broader application of cross-correlation raised a number of additional complications (Robinson, 1978; Southam and Hay, 1978; Mann, 1979; Rock, 1988). First, both sections must be measured and sampled in equal increments of rock thickness for the two series to be mathematically comparable. Second, this basic approach is unable to accommodate the inevitable changes in sedimentation rate through time and between the two sections. These changes in rate must be corrected for by routines that stretch or shrink sections to find the best correlation. The resulting increased complexity of these methods apparently did not result in significantly improved correlations and their results were described as discouraging and disappointing (Mann, 1979). Davis (1986) stated that "these efforts have met with a notable lack of success, except in special circumstances," such as varve correlation. Ultimately, cross-correlation for stratigraphic correlation fell into disuse.

Correlations of sedimentary cycles can be considered one of Davis' (1986) special circumstances, because like varves, cycles are packages of rock bounded by correlative surfaces. Cycle thickness is recorded as a function of cycle number, not stratigraphic position. Because changes in sedimentation rate and cycle period control cycle thickness, they allow the sections to be correlated instead of being obstacles to the method. Ideally, one section should contain more cycles than the other and the short section should correlate entirely within the interval of the longer section. Identifying distinctive stratigraphic markers at the top and base of the section, such as prominent sequence stratigraphic surfaces, event beds, or biostratigraphic datums, can achieve this. In addition, the sections should lack significant unconformities. At a minimum, the location of such unconformities should be known so that erroneous cross-correlations can be detected. Finally, sections must be of sufficient length—at least several cycles long—for cross-correlation to produce meaningful results.

Cross-correlation of cycles cannot be used in cases where the locations of the outcrops experienced peaks in sediment supply at different points in time. For example, cross-correlation could erroneously correlate two sections widely spaced along depositional dip by matching the upward thickening of cycles within the lowstand systems tract of the downdip outcrop with that of the highstand systems tract of the updip outcrop. Likewise, cross-correlation would incorrectly correlate cycles in a series of clinoforms because it would tend to match the thickest cycles in each section. In reality, these thickest cycles in each outcrop would be successively younger towards the center of the basin. Because of these problems, cross-correlation will work best for sections that are closely spaced geographically or from sections on flat-topped platforms that experience nearly synchronous changes in accommodation and sediment supply.

Where conditions permit its use, cross-correlation can provide a start to high-precision correlations, particularly in rocks that lack distinctive event beds or cycles that are readily distinguished from other cycles; in other words, apparently monotonous successions. In cases like these, cross-correlation may represent the only way that short sections in areas of limited exposure can be correlated to long sections. The method of cross-correlation will work only to the extent that subsidence rate and long-term sedimentation rate are relatively consistent between outcrops. Over short time scales of several dozen cycles and over short distances dominated by flexural rather than fault-controlled subsidence, these conditions are likely to be true. If longer period cycles or trends are present in the section that give rise to multiple possible correlations, other geologic criteria, including the presence of fossils, can be used to choose among the correlations. In this way, cross-correlation does not fully automate the process of correlation, but is used to narrow the range of potential correlations that can be selected by other geologic data. In addition, cross-correlation permits the calculation of confidence levels on the correlation, thereby providing a standard for the robustness of the correlation.

The method presented here is attractive because it can be applied quickly once the longer sections are described. Although bed-by-bed measurement and faunal description of the K445 section took place over several weeks (largely because every bed thicker than 5 mm was described), the White Castle section was measured and described in a little over an hour and a half. No attempt was made at White Castle to measure every bed or thoroughly describe the fauna. Major limestone beds defining cycle boundaries were measured and a quick tally of the common fossils was made. Because not all sections have to be described to the detail of the thicker primary outcrops, correlation of numerous small outcrops can proceed rapidly.

CONCLUSIONS

(1) The combination of cross-correlation of meter-scale cycles, supplemented by patterns of fossil occurrence, can permit high-resolution correlations in successions previously considered to be monotonous. Even facies fossils can be sufficient for distinguishing among potential correlations suggested by cross-correlation. This approach has particular promise in areas lacking distinctive event beds or other marker horizons and in areas of limited outcrop where numerous small sections need to be correlated to a few more widely spaced, thicker, and better described outcrops. Cross-correlation also allows a quantified measure of the statistical confidence of the correlation, unlike traditional methods. Finally, the method described here can be employed rapidly once the initial detailed descriptions of the primary localities have been made.

(2) Although cross-correlation was used widely in the 1960s and 1970s as a means of correlation, but then largely abandoned, it has potential use in correlating meter-scale cycles over short distances where significant unconformities are absent. Such use is much closer to the original and highly successful application of cross-correlation to varves than the more disappointing results obtained when the method was later applied to geophysical well logs.

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APPENDIX

Locality descriptions

White Castle. Roadcut on hillside, immediately east and behind White Castle processing plant, located on Kentucky State Route 17, 1.5 kilometers south of I-275 overpass. Covington, KY-OH 7 1/2′ quadrangle. 39° 00′ 30″ N, 84° 31′ 47″ W.

K445 Composite. Composite outcrop consists of four sections: K445, CON1, CON2, and CON3. K445: Roadcut on both sides of Kentucky State Route 445, 0.2 km west of intersection with Kentucky State Route 8, immediately northwest of the I-275 bridge over the Ohio River near Old Coney Amusement Park. Newport, KY-OH 7 1/2′ quadrangle. 39° 03′ 22″ N, 84° 26′ 10″ W. CON1: First roadcut on northwest side of westbound I-275, 0.5 km southwest of intersection of I-275 and the Kentucky bank of Ohio River near Old Coney Amusement Park. Newport, KY-OH 7 1/2′ quadrangle. 39° 03′ 15″ N, 84° 26′ 20″ W. CON2: Second roadcut on northwest side of westbound I-275, 0.6 km southwest of intersection of I-275 and the Kentucky bank of Ohio River near Old Coney Amusement Park. Newport, KY-OH 7 1/2′ quadrangle. 39° 03′ 13″ N, 84° 26′ 24″ W. CON3: Third roadcut on northwest side of westbound I-275, 0.8 km southwest of intersection of I-275 and the Kentucky bank of Ohio River near Old Coney Amusement Park. Newport, KY-OH 7 1/2′ quadrangle. 39° 03′ 10″ N, 84° 26′ 30″ W.