CONODONTS AND THE CAMBRIAN–ORDOVICIAN BOUNDARY IN WISCONSIN

Brian P. Parsons[1] *and David L. Clark*[1]

ABSTRACT

For more than 100 years, the Cambrian–Ordovician boundary in the Upper Mississippi Valley, the original type area of the North American Upper Cambrian, has been considered to approximate the contact of the Jordan Formation (Cambrian sandstone) and the Oneota Formation (Ordovician dolomite). Earliest judgments on this sandstone–dolomite systemic contact were based on trilobites, but our recent work with conodonts constrains these earlier determinations. Conodonts that are known to range through several Ibexian (=Early Ordovician) conodont zones are found on either side of the Jordan Formation–Oneota Formation lithologic contact in southern Wisconsin and suggest that no matter which of the four candidates for the international Cambrian–Ordovician boundary (the base of the Cordylodus proavus *Zone, the base of the* Cordylodus intermedius *Zone, the base of the* Cordylodus lindstromi *Zone, and the base of the* Iapetognathus *Zone) ultimately is selected, the Cambrian–Ordovician boundary in the Upper Mississippi Valley will lie in the Jordan Formation and its equivalents and not at the younger sandstone–dolomite contact. In addition, the identification of conodont species of similar age that range through several zones in sandstones and dolomites suggests that what has been described as an unconformity at the traditional boundary may be relatively minor, at least in Wisconsin. In other areas, there may be unconformities of greater magnitude or additional unconformities at other horizons in the Jordan.*

INTRODUCTION

The contact between the Jordan sandstone and the overlying Oneota dolomite in parts of the Upper Mississippi Valley traditionally has been considered to be a close approximation of the Cambrian–Ordovician boundary. The significance of this assignment relates to the fact that this traditional sandstone–dolomite contact originally served as the reference section for the systemic boundary in North America. However, data concerning the precise nature of the actual systemic boundary are not firm, and the purpose of this study was to use conodonts to more closely define this boundary in southern Wisconsin as well as to comment on the magnitude of the Jordan–Oneota stratigraphic unconformity.

Studies of the formations involved in the systemic boundary definition date back into the nineteenth century, when Winchell (1874) described the Jordan Formation in south-central Wisconsin and in the Minnesota and Mississippi River Valleys. Later, McGee (1891) defined the overlying Oneota Formation as the lower unit of the Prairie du Chien Group in the same general areas where the Jordan was studied. Later work by Ulrich (1924), Twenhofel and others (1935), Ostrom (1967), Miller and Melby (1971), Odom and Ostrom (1978), Runkel (1994), and Byers and Dott (1995) elaborated on the early definitions and added additional details concerning the two formations. Most recently, Hughes and Hesselbo (1997) have contributed new information regarding the lithologic details of part of this Saukian interval and its importance in understanding the North American type Upper Cambrian.

Ulrich (1924) noted that the Jordan–Oneota contact was unconformable, and much later, Ostrom (1964, 1970) agreed and stressed the relatively minor nature of the unconformity. In spite of the general agreement on the nature of the unconformable contact, recognition of the exact stratigraphic position of the contact between the formations as well as the systemic boundary remained controversial. For example, because the contact at many localities involves sandy dolomite that could not be clearly defined as either Jordan or Oneota, Odom and Ostrom (1978) informally proposed that the transition beds of sandstone and dolomite be called the Coon Valley Member. They assigned the

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new member to the Jordan Formation and assumed that this would permit a more consistent stratigraphic definition of the contact. Smith and others (1993) argued with this interpretation and showed that sandy dolomite and sandstone intervals such as that designated as the Coon Valley also are found in younger parts of the Oneota. According to Smith and others (1993), the Coon Valley designation did not solve the problem of providing a uniform stratigraphic horizon for the lithostratigraphic boundary because of the repetitive nature of the Coon Valley lithology in younger horizons of the Oneota. Also, the base of the Coon Valley lithology is an unconformable surface; its top is gradational, with sandstone diminishing in abundance upward. Because of this, Smith and others (1993) reassigned the Coon Valley interval to the lower part of the Oneota. Later, Runkel (1994) reached a similar conclusion. This definition places the unconformity at the base of the redefined Oneota. The Oneota consists of the first major dolomite to appear above the Upper Cambrian sandstone, at least in southern Wisconsin. Because the sandstone and dolomite at the Jordan–Oneota contact have been interpreted to be both gradational and unconformable, the location of the traditional Cambrian–Ordovician boundary becomes a question and results in a more ambiguous definition of the Cambrian–Ordovician boundary in the Upper Mississippi Valley. Was the actual Cambrian–Ordovician boundary within the Jordan sandstone, the Coon Valley mixed lithology, or the Oneota dolomite?

Byers and Dott (1995) addressed the lithostratigraphy of the Jordan Formation, as had Runkel earlier (1994), but they suggested that it is composed of two "coarsening upward" progradational cycles incised by an unconformity at the base of the dolomite of the Oneota. They noted that at some localities an entire Jordan sandstone cycle may be missing because of the unconformity. These observations suggested that the Jordan–Oneota unconformity is more significant than was recognized earlier, but renewed the question of the actual location of the Cambrian–Ordovician boundary within this sequence.

For this study, we relied on the earlier work of Byers and Dott (1995), who studied the Jordan–Oneota relationship in southern Wisconsin. The unconformable contact between these formations is evident at most of the localities we studied and consists of a prominent erosion surface at the top of the Jordan (for example, Byers and Dott, 1995; Miller and Runkel, 1998). The unconformity is evident because the white cross-stratified sandstone of the Van Oser Member is irregularly cut and filled with the gray, oolitic, intraclastic dolomite of the Oneota (for example, fig. 15 of Byers and Dott, 1995). Although very slightly dolomitic sandstones are known lower in the Jordan, no major dolomites have been observed lower in any of the sections we studied and we agree with the clear definition of this contact as defined by Byers and Dott (1995).

CAMBRIAN–ORDOVICIAN BOUNDARY AND CONODONTS

Byers and Dott (1995) reported that evidence for the Late Cambrian age of the Jordan Formation is based on trilobites identified as *Tellerina strigosa* Ulrich and Ressor, a species found in the *Saukia* Zone underlying the uppermost Cambrian *Eurekia apopsis* Zone and restricted to the Late Cambrian. Because specimens of *Tellerina* were not collected from sections showing the complete Jordan–Oneota sequence, the spatial relationship of the several specimens to the base of the Oneota was not determined. However, it is estimated that the specimens, collected in the Madison area, were from a level between 2 and 5 m below the unconformity at the base of the Oneota (R.H. Dott, University of Wisconsin–Madison, verbal communication, 1996). In the flat-lying Cambrian–Ordovician strata in southern Wisconsin, this estimate probably is realistic. The top of the *Saukia* Zone is correlated with the base of the *Cordylodus proavus* conodont zone (fig. 1). Because trilobites from the lower part of the Oneota Formation are identified with the *Symphysurina* Zone of the Early Ordovician (Heller, 1956), the trilobite evidence suggests that the traditional Cambrian–Ordovician boundary approximates the lithologic boundary. However, the absence of trilobites or conodonts in the interval between the highest interval containing *Tellerina* and the Ordovician conodonts in the upper Jordan has not permitted a more precise stratigraphic designation.

Because conodonts have been found in the uppermost beds of the Jordan as well as the basal-most beds of the Oneota (Miller and Melby, 1971; Smith and Clark, 1996), we studied exposures of the Jordan–Oneota contact at eight localities in Wisconsin and Minnesota (fig. 2). At the localities, we observed more or less the same physical relationship as that at our key Miller's Curve section (figs. 2 and 3), and we believe that the Jordan–Oneota contact was correctly identified. This conclusion is based on examination of all exposures adjacent to the specific localities. We also considered elevations in the relatively flat-lying lower Paleozoic rocks, and, in addition, relied on guidance from those who have worked on the

<table>
<tr><th rowspan="3">SERIES</th><th colspan="2">TRILOBITE ZONATION</th><th colspan="2">CONODONT ZONATION</th></tr>
<tr><th colspan="2">STITT (1977)</th><th colspan="2">MILLER (1988)</th></tr>
<tr><th>ZONE</th><th>SUBZONE</th><th>ZONE</th><th>SUBZONE</th></tr>
<tr><td rowspan="13">IBEXIAN (part)</td><td rowspan="8">Symphysurina</td><td>S. woosteri</td><td colspan="2">Rossodus manitouensis</td></tr>
<tr><td rowspan="3">Symphysurina bulbosa</td><td colspan="2">Cordylodus angulatus</td></tr>
<tr><td colspan="2">Iapetognathus</td></tr>
<tr><td colspan="2" rowspan="2">Cordylodus lindstromi</td></tr>
<tr><td rowspan="4">Symphysurina brevispicata</td></tr>
<tr><td rowspan="3">Cordylodus intermedius</td><td>Clavohamulus hintzei</td></tr>
<tr><td rowspan="2">Hirsutodontus simplex</td></tr>
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<tr><td rowspan="4">Missisquoia</td><td rowspan="2">Missisquoia typicalis</td><td rowspan="5">Cordylodus proavus</td><td rowspan="2">Clavohamulus elongatus</td></tr>
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<tr><td rowspan="2">Missisquoia depressa</td><td>Fryxellodontus inornatus</td></tr>
<tr><td rowspan="2">Hirsutodontus hirsutus</td></tr>
<tr><td rowspan="7">Saukia</td><td>Eurekia apopsis</td></tr>
<tr><td rowspan="8">CROIXIAN (part)</td><td>Saukiella serotina</td><td rowspan="2">Eoconodontus</td><td>Cambrooistodus minutus</td></tr>
<tr><td rowspan="2">Saukiella junia</td><td>Eoconodontus notchpeakensis</td></tr>
<tr><td colspan="2" rowspan="2">Proconodontus muelleri</td></tr>
<tr><td rowspan="3">Rasettia magna</td></tr>
<tr><td colspan="2">Proconodontus posterocostatus</td></tr>
<tr><td colspan="2" rowspan="2">Proconodontus tenuiserratus</td></tr>
<tr><td rowspan="2">Saratogia</td><td rowspan="2">(UNNAMED)</td></tr>
<tr><td colspan="2">No Zonation Established</td></tr>
</table>

Figure 1. *Conodont and trilobite zonation of the Late Cambrian and Early Ordovician (adapted from Miller, 1988).*

particular outcrops previously. We sampled the rocks immediately adjacent to the contact in greatest detail. Four of the exposures yielded conodonts, two of them (localities 4 and 6, fig. 2) in significant numbers (fig. 4). Samples that did not yield conodonts were primarily sandstone and sandy dolomite, even though several kilograms of each lithologic type were desegregated in the lab. From the productive samples, we made the following conclusions:

1. Conodonts from either side of the Jordan–Oneota unconformity include the same species, with two exceptions. No elements of *Cordylodus lindstromi* were found in the Jordan, and no elements of *Variabiloconus bassleri* were found in the Oneota at our localities. *Variabiloconus bassleri* is known in the Oneota at other localities that were not part of this study (for example, Smith and Clark, 1996), but *C. lindstromi* has not been reported anywhere in the Jordan.

2. The conodonts from the uppermost Jordan and lowermost Oneota are species that range from the Ibexian *Cordylodus proavus* Zone into the Ibexian *Rossodus manitouensis* Zone. If the questionable *Cordylodus proavus* specimen is not considered (fig. 4), the remaining species still range from the upper part of the *Cordylodus intermedius* Zone into the *Rossodus manitouensis* Zone. This is a range of four conodont zones (fig. 1) in the Early Ordovician Ibexian and is equivalent to the *Symphysurina* trilobite zone of the Early Ordovician. Clearly, the uppermost beds of the Jordan are Early Ordovician and contain the same species (except as noted above) as those in the well established overlying Early Ordovician Oneota Formation.

3. The presence of essentially the same species of conodonts across the lithologic unconformity that separates the Jordan and the Oneota suggests that the unconformity is relatively minor, at least at the several localities where we obtained faunas. Miller and Runkel (1998) reported species of the Cambrian genus *Proconodontus* lower in the Jordan at localities in Minnesota. Unfortunately, no single locality has been identified that yields the Late Cambrian *Proconodontus,* the Late Cambrian trilobite *Tellerina,* and the Ibexian conodonts reported here. However, the several conodont zones apparently missing between Miller's report of *Proconodontus* in Minnesota and our Ibexian species at the top of the Jordan in southern Wisconsin suggest that there may be multiple unconformities in the upper part of the Jordan in addition to the one at the Jordan–Oneota contact or larger unconformities in Minnesota than in Wis-

Figure 2. *Jordan–Oneota boundary sections studied. 1. Boscobel, SW½, NW½, section 21, T8N, R3W, Grant County, Wisconsin; 2. Cross Plains East, NW½, SW½, sec. 11, T7N, R7E, Dane County, Wisconsin; 3. Denzer, quarry approximately 0.5 mi SE of Denzer, north side of Highway C, NW½, SE½, sec. 14, T10N, R5E, Sauk County, Wisconsin; 4. Mazomanie, approximately 3 mi SW of Mazomanie, south side of Highway K, NW½, NE½, sec. 31, T8N, R6E, Dane County, Wisconsin; 5. Mendota Station, railroad cut in center sec. 26, T8N, R9E, Dane County, Wisconsin; 6. Miller's Curve, roadcut approximately 2.5 mi SE of Cross Plains, north side of Highway 14, SW½, SE½, section 7, T7N, R8E, Dane County, Wisconsin; 7. Spring Valley, approximately 0.25 mi north of Spring Valley, NW½, NW½, sec. 5, T27N, R15E, Pierce County, Wisconsin; 8. Weaver, SW½, SW½, sec. 30, T109N, R9W, Wabasha County, Minnesota.*

consin. Miller and Runkel (1998, fig. 9) indicated that the major unconformity in the area of Homer, Minnesota, is at the Jordan–Oneota contact, and at that locality as many as eight conodont zones representing the upper Trempealeauan and lower Skullrockian are missing. This suggests that the unconformity at the Minnesota section is more profound and includes part of the Jordan that is present in southern Wisconsin.

Recent studies by the International Working Group on the Cambrian–Ordovician Boundary (IWGCOB) have shown that the Cambrian–Ordovician boundary has been inconsistently designated at different localities and is not at the same stratigraphic level worldwide. Reasons for this generally reflect the fact that different fossils are used by different investigators in their stratigraphic definitions, and there has not always been a clear understanding of how the different fossil occurrences correlate with each other. The IWGCOB has decided that a standardized international boundary should be based on conodont, graptolite, and trilobite definitions (Miller, 1988).

Conodont-based candidates for the international boundary are 1) the base of the *Cordylodus proavus* Zone; 2) the base of the *Cordylodus intermedius* Zone; 3) the base of the *Cordylodus lindstromi* Zone; or 4) the base of the *Iapetognathus* Zone (Miller, 1988; Ross and others, 1993; Miller and Taylor, 1995) (fig. 1). Assuming that one of these zonal boundaries is selected, it is apparent that the Cambrian–Ordovician boundary is in the Jordan Formation and definitely below the Jordan–Oneota contact as we recognize it in southern Wisconsin, the traditional level.

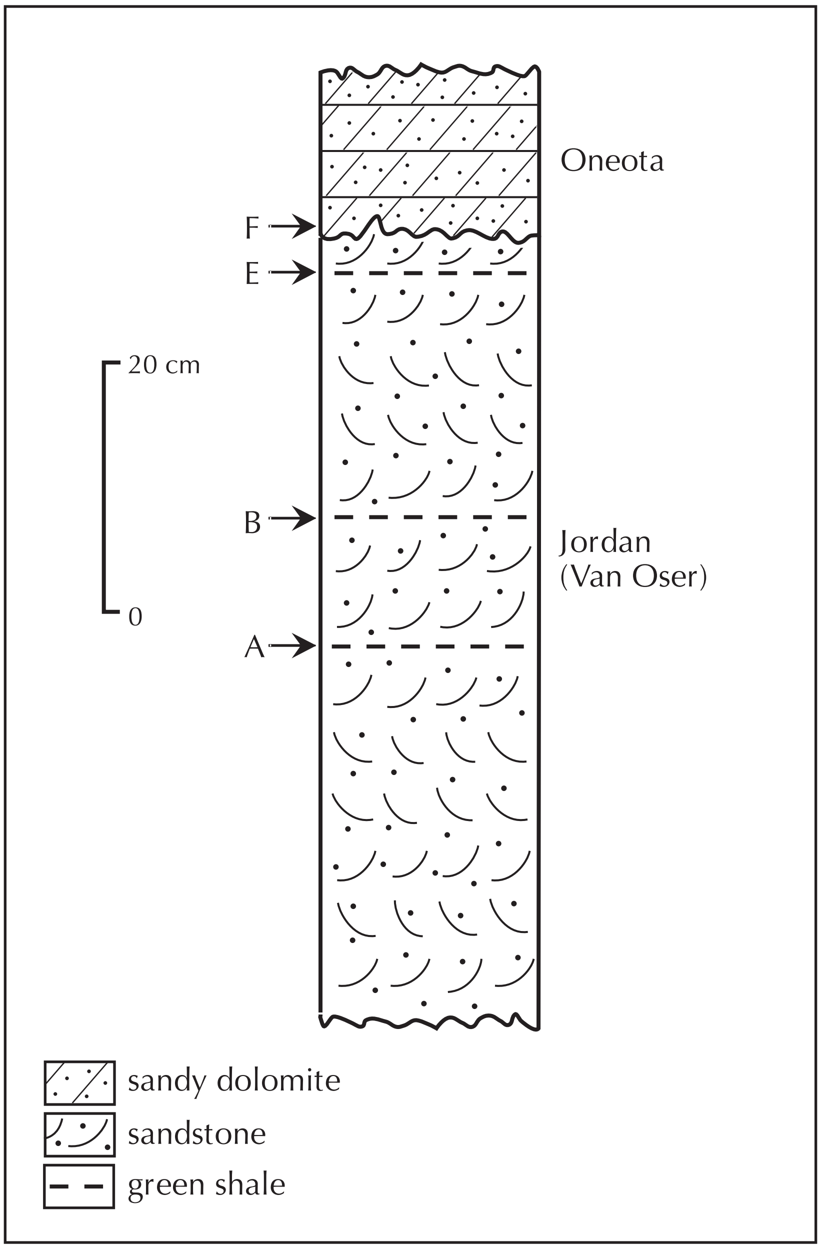


Figure 3. *Oneota–Jordan relationship at Miller's Curve (locality) a few miles west of Madison. Letters and arrows indicate important samples that yielded conodonts (fig. 4). Essentially, the same relationship of lithostratigraphic units shown here for Miller's Curve is found at each of the other localities studied (fig. 2).*

CONODONTS AND THE JORDAN–ONEOTA INTERVAL

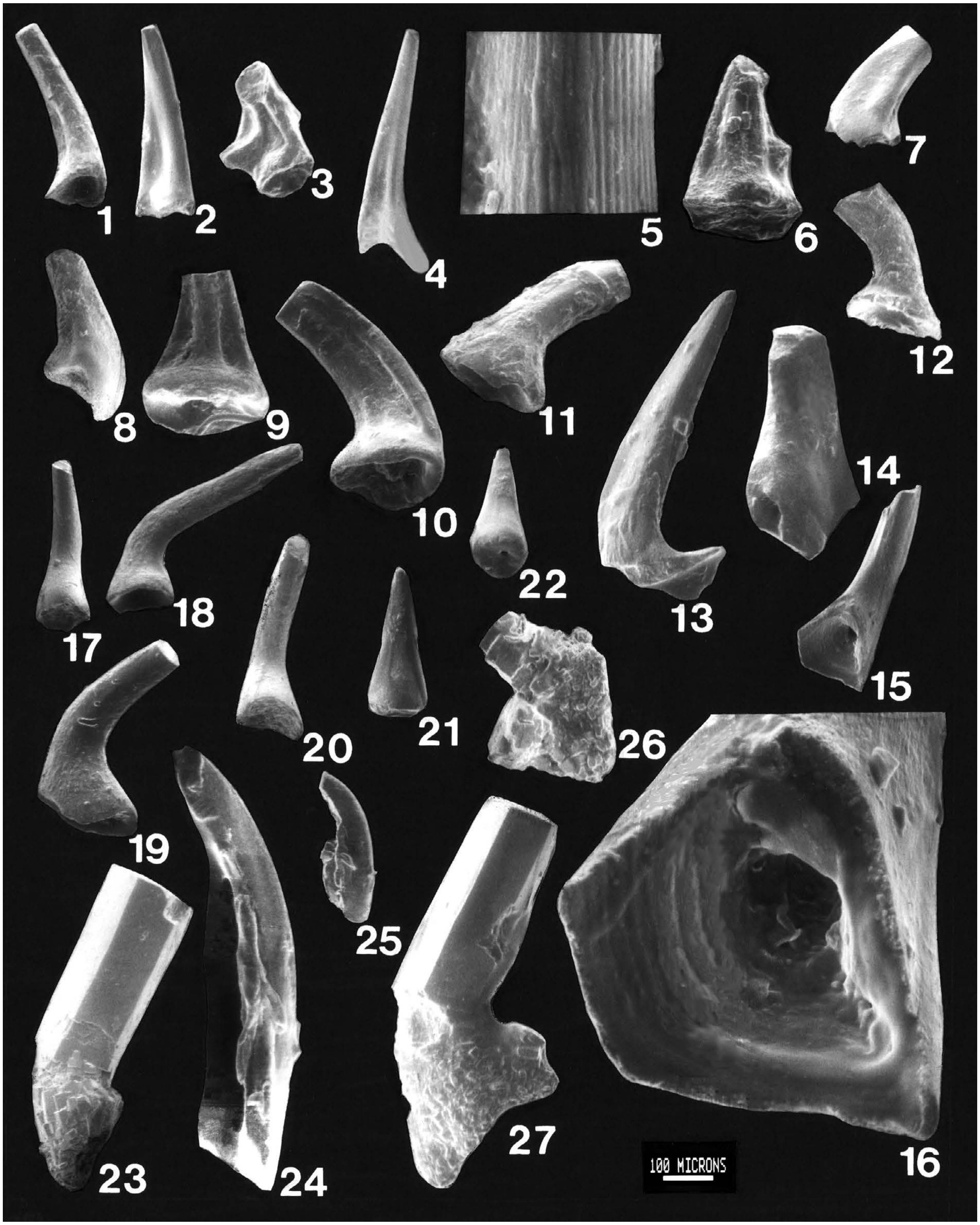
The Ibexian conodonts of the Jordan and lower Oneota (figs. 4 and 5) include species that represent shallow subtidal and possibly supratidal as well as further offshore assemblages. We interpret the *Teridontus* and

	Locality 6 Samples						Locality 3	Locality 4	Locality 7
Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Acanthodus uncinatus Furnish		3	6	15	6	4		6	
Aloxoconus sp.					3	7		5	
Aloxoconus iowensis (Furnish)			8	9	7	3		4	
Aloxoconus propinquus (Furnish)	1		12	8	1	2		2	1
Aloxoconus staufferi (Furnish)			4	2	2			4	
Cordylodus lindstromi Druce and Jones						4			
Cordylodus proavus Müller	1?								
Oneotodus simplex (Furnish)			29	61	34	13	1	44	
Teridontus nakamurai (Nogami)		1	55	131	71	78	3	107	1
Variabiloconus bassleri (Furnish)			5	6			2	1	

▲ **Figure 4.** *Conodonts from the Jordan–Oneota contact area, Wisconsin. Samples A–F are from locality 6 (figs. 2 and 3), G, H, and I are from localities 3, 4, and 7 (fig. 2). A. Lower shale of Van Oser Member of Jordan Formation, 30 cm above base of Van Oser, center of roadcut. B. Intermediate shale of Van Oser Member of Jordan Formation, 40 cm above base of Van Oser, center of roadcut. C. Same as A, west end of roadcut. D. Same as A, east end of roadcut. E. Uppermost green shale of Van Oser Member of Jordan Formation, 61 cm above base of Van Oser, 3 cm below Jordan–Oneota contact, center of roadcut. F. Base of lowermost dolomite of Oneota Formation, center of roadcut. G. Locality 3, green shale lenses of Van Oser Member, 20 cm below Jordan–Oneota contact. H. Locality 4, green shale lenses of Van Oser Member, 10 cm below Jordan–Oneota contact. I. Locality 7, green shale lenses of Van Oser Member, 9 cm below Jordan–Oneota contact. All shale samples were treated in water; dolomites and sandy dolomite were treated with acetic and/or formic acid. Residues were washed on a 120 mesh screen and were concentrated in tetrabromoethene. As much shale as could be sampled was taken at each outcrop (up to 1 kg), and up to 5 kg of the dolomites and sandy dolomites were sampled.*

▶ **Figure 5.** *Conodonts from the Jordan–Oneota contact area in Wisconsin. All specimens are x100, except as indicated. Specimens are in the Museum of the Department of Geology and Geophysics of the University of Wisconsin–Madison, UW1904.*

1–5, Aloxoconus propinquus *(Furnish), 1–3, posteriolateral views, 1, sample D, locality 6, UW1904/15, 2, sample C, locality 6, UW1904/16, 3, sample F, locality 6, UW1904/17; 4–5, posterior and enlargement (x1000) showing microstriations, sample C, locality 6, UW1904/18.*
6–7, Aloxoconus staufferi *(Furnish), 6, posterior, sample C, locality 6, UW1904/13, 7, lateral, sample H, locality 4, UW1904/14.*
8–9, Aloxoconus iowensis *(Furnish), 8, lateral, sample D, locality 6, UW1904/12, 9, posterior, sample H, locality 4, UW1904/11.*
10–11, Variabiloconus bassleri *(Furnish), 10, posteriolateral, sample D, locality 6, UW1904/7, 11, lateral, sample C, locality 6, UW1904/8.*
12–16, Acanthodus uncinatus *Furnish, 12, lateral, sample D, locality 6, UW1904/20, 13, lateral, sample B, locality 6, UW1904/9, 14, posteriolateral, sample H, locality 4, UW1904/7, 15, posterior and 16, basal cavity showing lamellae, x500, sample H, locality 4, UW1904/10.*
17–18, 23, Teridontus nakamurai *(Nogami), 17, posterior, sample E, locality 6, UW1904/6, 18, lateral, sample D, locality 6, UW1904/5, 23, lateral showing apatite overgrowth on cusp, sample B, locality 6, UW1904/2.*
19–20, Oneotodus simplex *(Furnish), 19, lateral, sample D, locality 6, UW1904/2, 20, posterior, sample H, locality 4, UW1904/3.*
21–22, Aloxoconus sp. *?, 21, posterior and 22, basal, sample H, locality 4, UW1904/23.*
24–25, Cordylodus proavus *Müller?, 24, posterior-lateral, X300, and 25, lateral, sample A, locality 6, UW1904/22.*
26–27, Cordylodus lindstromi *Druce and Jones, 26, specimen with projection of basal cavity into first broken denticle base (not shown), sample F, locality 6, UW1904/19, 27, specimen with main cusp recrystallized, sample F, locality 6, UW1904/1.*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Variabiloconus–Aloxoconus assemblage of the Jordan to represent the shallow subtidal to intratidal environment. In contrast, the conodont assemblage of the Oneota may represent a slightly deeper subtidal facies. This interpretation is consistent with recent work with the Lower Ordovician St. George Group of western Newfoundland (Ji and Barnes, 1994) that included many of the same species as our Upper Mississippi Valley section.

The conodonts from the Jordan were recovered primarily from centimeter-scale shale partings in a sandstone matrix (for example, fig. 3). These very thin shale intervals are discontinuous laterally, never more than 1 cm thick, and their relationship to the enclosing sandstone must be considered. We believe that these tiny shale partings represent tidal deposits of the fine-grained material carried to the site of deposition by tidal surges and then deposited during time of slack tide, similar to the earlier interpretations of Runkel (1994) and Byers and Dott (1995). During the succeeding tidal surges, most of the fine-grained material was probably removed. This explains the very thin and discontinuous nature of the shales. The only fine-grained sediment remaining was that which was trapped in the more protected parts of the undulating sand bottom. Conodonts living in this shallow zone also left a record in the fine-grained sediment. Analogous sedimentation has been described for other parts of the Upper Mississippi Valley Cambrian sediment (Dott and others, 1986; Haddox and Dott, 1990) and is consistent with more recent interpretations of the Jordan (Byers and Dott, 1995). This suggests to us that the unconformity at the Jordan–Oneota contact is relatively minor and was produced by subaerial erosion during hundreds or thousands of years, or perhaps during an even shorter interval. Additional unconformities probably exist lower in the section (fig. 6), at least in Minnesota if the interpretation of Miller and Runkel (1998, fig. 9) is accepted.

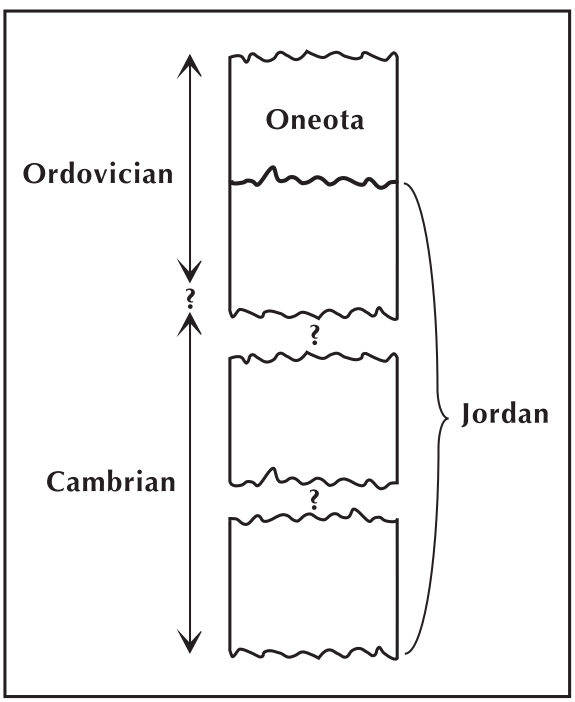

Figure 6. *Cambrian–Ordovician relationship of the Oneota and Jordan. Major unconformities may be present lower in the Jordan and would account for the missing conodont zones suggested by Miller and Runkel (1998) in Minnesota.*

As interpreted, the most significant difference between the conodonts of the uppermost Jordan and the lowermost Oneota may have been environmental. There are not significant faunal differences.

SUMMARY

The nearshore region of the epeiric sea surrounding the North American cratonic interior was a sand shoal during the Late Cambrian and Early Ordovician. The shallow water sands prograded over the deeper water sands at least twice during deposition of the Jordan. The Jordan–Oneota unconformity which has been considered to represent the Cambrian–Ordovician boundary probably is relatively minor in southern Wisconsin, as suggested from the conodonts that range across it. However, there are localities where the unconformity cuts down into the sands of the Jordan Formation to varying degrees, in some places possibly eliminating an entire progradational cycle (Byers and Dott, 1995) or several Late Cambrian–Early Ordovician conodont zones (Miller and Runkel, 1998). This may have occurred during a relatively short time interval. There may be other unconformities lower in the Jordan as well (fig. 6). The sea level fall and its subsequent rise were rapid and occurred during the time of formation of one or several of the closely related Ibexian conodont intervals (fig. 1). Although the amount of time represented by the conodont ranges or the zones is not known with precision, it probably does not represent more than a few hundred thousand years. The similarity of conodonts of the uppermost Jordan and the lowermost Oneota constrains the magnitude of the unconformable lithologic contact to the range of the several species reported here, but probably does not represent a major interval of geologic time. The late Cambrian trilobite *Tellerina strigosa* of the upper Jordan (uppermost *Saukia* Zone) has been found only a few meters below the Ibexian conodonts of the Jordan. This indicates that the uppermost Jordan, at least in southern Wisconsin, is Ordovician (figs. 1 and 6) according to any of the possible boundaries that might be selected by the IWGCOB. If our interpretation is correct, the Cambrian–Ordovician boundary in this part of the Upper Mississippi Valley is lower than the Jordan–Oneota lithologic contact.

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