Sequence Stratigraphy at the Turn of the Century: E.O. Ulrich's Ozarkian System in Wisconsin

Charles W. Byers[1]

ABSTRACT

Edward Oscar Ulrich (1857–1944) was a major force in North American paleontology and stratigraphy, especially of the Paleozoic Era. Ulrich was immersed in correlation problems for many years; he came to believe that although fossils could tell the age of given strata, they were unsuitable for defining boundaries in the stratigraphic record. Instead, he advocated the use of erosional breaks—subaerial unconformities and transgressive surfaces—as natural and unambiguous boundaries for chronostratigraphic units, anticipating the heyday of sequence stratigraphy by many decades. His 1911 article Revision of the Paleozoic Systems *defined two extra systems, the Ozarkian and the Canadian, as lying between the Cambrian and the Ordovician. According to Ulrich, although Ozarkian strata are thin in Wisconsin, it is here that the lower boundary of the system is best developed as a basal conglomerate (Devils Lake Sandstone) exposed in the vicinity of the Baraboo Range. The ultimate failure of the Ozarkian to survive as a system was based on Ulrich's miscorrelation of unconformities. His inability to determine the exact age of erosion surfaces led him to accumulate too many boundaries (and hence too many chronostratigraphic units) in his composite stratigraphic column. Sequence stratigraphers face exactly the same problem today.*

INTRODUCTION

Edward Oscar Ulrich (shown in his later years in fig. 1) began his career as a paleontologist in 1864 at the age of seven, when he first saw fossils in the rocks of his native Cincinnati (Bassler, 1945). As an amateur and later as an employee of various state surveys and eventually the U.S. Geological Survey, he collected and classified huge numbers of Paleozoic marine invertebrates. He focused especially on groups that required painstaking attention to detail, such as the bryozoans, sponges, and ostracodes, but he also published extensively on mollusks and trilobites. His taxonomic expertise was put to use in biostratigraphy because the state surveys subdivided the geologic systems in North America primarily on the basis of fossils. Ulrich believed that fossil species should be established on the basis of very slight morphological variations—that is, he was a splitter—and that these species could be used to correlate stratigraphic units of very short time duration.

However, he recognized that there were problems with biostratigraphic correlation, especially the problem of defining the boundaries of stratigraphic units. Fossils might give the age of an interval, but their uneven distribution made them poor markers for the interval's base and top. So he turned to another method of subdivision, using erosional breaks in the stratigraphic record, what we now call sequence stratigraphy. In his own words:

> *In short, we require something that will supply the deficiencies of the purely paleontologic and lithologic methods, and thus assure greater definiteness in the delimitation of stratigraphic and time units. The means is at hand. It lies among those criteria of diastrophism . . . indicating alternate advance and retreat—displacement—of the strand line (Ulrich, 1916, p. 468).*

> *Concisely stated, the method followed is to divide the stratigraphic sequence at the first plane beneath the introduction of a new fauna or beneath a marked faunal change that exhibits evidence of diastrophic movements (Ulrich, 1911).*

[1]University of Wisconsin, Department of Geology and Geophysics, 1215 W. Dayton Street, Madison Wisconsin 53706

Figure 1. E.O. Ulrich taking notes in the field (Wisconsin Geological and Natural History Survey photograph 459).

These stratigraphic breaks—subaerial unconformities and transgressive surfaces—provided unambiguous natural boundaries and allowed Ulrich to revise the entire Paleozoic stratigraphic column. This revision (Ulrich, 1911) is 400 pages long, and yet it is incomplete; the detailed stratigraphic descriptions reach upward only to the Lower Ordovician!

OZARKIAN AND CANADIAN SYSTEMS

Ulrich's revision added two new stratigraphic systems between the Cambrian and the Ordovician. In the Appalachians and much of the midcontinent, the Cambrian–Ordovician boundary is obscure, lying within a thick sequence of carbonates that are not very fossiliferous. Ulrich believed that these poorly fossiliferous carbonates encompassed two geologic systems, lying above the fossiliferous Cambrian rocks and below similarly well defined Ordovician rocks. He named the new systems the Ozarkian and the Canadian (Weiss and Yochelson, 1995).

Table 1. *Ulrich's revised Lower Paleozoic.*

System	Formations	Type area
	Bellefonte	Pennsylvania
CANADIAN	Axeman	Pennsylvania
	Nittany	Pennsylvania
	Stonehenge	Pennsylvania
	Jefferson City	Missouri
	Roubidoux	Missouri
	Gasconade	Missouri
OZARKIAN	Proctor	Missouri
	Copper Ridge	Tennessee
	Potsdam	New York
	Potosi	Missouri
	Ketona	Alabama
	Briarfield	Alabama
	Nolichucky	Tennessee
	Maryville	Tennessee
CAMBRIAN	Rogersville	Tennessee
	Rutledge	Tennessee
	Russell	Virginia

The type formations for the new systems are shown in table 1. Notice that the Canadian units are all from Pennsylvania, but the Ozarkian formations are from Missouri, New York, and the southern Appalachians. We now know that the upper Ozarkian formations in Missouri are equivalent to the Canadian formations in Pennsylvania, and that both sets of units are of Early Ordovician age. They are lateral equivalents, but Ulrich stacked them vertically instead. Likewise, the lower Ozarkian units are actually Late Cambrian in age; Ulrich thought they were younger than that.

In summary, all the rocks assigned to the Ozarkian and Canadian are either Late Cambrian or Early Ordovician. Later geologists used "Canadian" as a series name, equivalent to Lower Ordovician, rather than as a full-fledged system as Ulrich proposed. But the Ozarkian, its component formations all reassigned, completely disappeared as a stratigraphic name at any level. In the words of Weiss and Yochelson (1995), it is a system "gone and nearly forgotten."

Table 2. Comparison of current classification of Wisconsin Cambrian units with Ulrich's classification.

Present column	**Ulrich (1924)**	
(Cambrian formations from Ostrom, 1967)	WESTERN WISCONSIN (Cambrian formations)	MADISON–BARABOO REGION (Cambrian and Ozarkian formations)
Jordan Formation	Jordan Sandstone Norwalk Sandstone	Madison Sandstone
St. Lawrence Formation	Lodi Shale St. Lawrence Limestone	 Mendota Dolomite Devils Lake Sandstone
		unconformity
Tunnel City Group	Franconia Formation	Mazomanie Sandstone
Wonewoc Formation	Dresbach Sandstone	Dresbach Sandstone
Eau Claire Formation	Eau Claire Shale	Eau Claire Shale
Mount Simon Formation	Mount Simon Sandstone	Mount Simon Sandstone

ULRICH AND WISCONSIN

What does all this have to do with Wisconsin? Ulrich spent time in the field here, and he recognized both of his new systems in the local stratigraphy. Table 2 compares the presently accepted stratigraphic column for the Cambrian formations in Wisconsin (Ostrom, 1967) with Ulrich's column, published in 1924 (also see Dunbar and Rodgers, 1957, p. 286). The formation terminology Ulrich used for western Wisconsin is similar to the present-day column. The Dresbach Sandstone has changed to "Wonewoc," and the Franconia and Mazomanie Formations (both glauconite-bearing sandstones) have been combined into the Tunnel City Group. Also, the Lodi Shale is recognized as a facies (member) of the St. Lawrence Formation, and the Norwalk as a member of the Jordan.

In the Madison–Baraboo area of south-central Wisconsin, Ulrich's column is distinctly different. He believed that the St. Lawrence, Lodi, Norwalk, and Jordan were missing because of post-Cambrian erosion. The unconformity was overlain by supposed Ozarkian strata: the Devils Lake Sandstone, Mendota Dolomite, and Madison Sandstone. As table 2 indicates, it is now understood that the Mendota Dolomite is simply a synonym for the St. Lawrence and the Madison Sandstone is really the Jordan. But Ulrich refused to accept them as Cambrian units; instead, he put them in the Ozarkian. Ulrich's paleogeographic scenario was as follows: In latest Cambrian time the St. Lawrence and Jordan were deposited across Wisconsin. Then in the Madison–Baraboo region only, the formations were eroded. The resulting erosion valley was filled in during Ozarkian time by a set of units that included two formations (Mendota and Madison) that mimicked amazingly the St. Lawrence and Jordan in lithology, thickness, and fossil content (Ulrich, 1916). Ulrich was driven to these stratigraphic gymnastics because of his interpretation of the formation that lay below the Mendota—the Devils Lake Sandstone, a conglomerate as much as 100 feet thick, exposed near Baraboo. That conglomerate is spectacular, with boulders of purple Precambrian Baraboo Quartzite enclosed in white sandstone. Ulrich reasoned that a basal conglomerate this thick must overlie a major unconformity, representing a huge break in deposition, one big enough to form the base of a whole geologic system, namely the Ozarkian: "the Devils Lake sandstone . . . affords a more impressive development and display of conglomerate than has been observed at this horizon anywhere else in America" (Ulrich, 1924, p. 104) and "the abundance and character of the conglomerates . . . prove to be the best objective evidence we have in establishing the verity of the break between the Cambrian and the Ozarkian" (Ulrich, 1924, p. 105).

So, even though Ulrich's Ozarkian System in Wisconsin was much thinner than in the Appalachians, its basal contact was remarkable, the best he had ever seen. Given that the Devils Lake was Ozarkian in age, the formations above it, the Mendota and the Madison, must also be Ozarkian.

Today we know that the "Devils Lake" conglomerates are facies developed in several Cambrian sandstone formations in the vicinity of the Baraboo ridges, which stood as islands in the Late Cambrian sea. During the Cambrian transgression, as the sea gradually inundated the weathered Precambrian surface, Baraboo Quartzite clasts were eroded from the islands and deposited nearby in the basal transgressive sands (Dalziel and Dott, 1970).

Where did Ulrich go wrong? The problem was, and is, that although unconformities provide unambiguous surfaces for boundaries, their ages are difficult to establish, so it is hard to correlate with them. One erosion surface looks much like another, so matching them in different locations is fraught with pitfalls.

Ulrich gave us a beautiful example of this in his 1916 discussion of field work near the town of Rock Springs (then called Ablemans), on the north limb of the Baraboo syncline. First he described an exposure of the Ozarkian contact, with its basal conglomerate, the Devils Lake Sandstone, full of boulders of Baraboo Quartzite. Here the unconformity at the base of the Devils Lake cuts into Dresbachian sandstone in the lower part of the Upper Cambrian. The middle and upper Upper Cambrian formations were absent, according to Ulrich: "the identifications . . . necessitated the assumptions that the Cambrian formations normally intervening . . . the Franconia sandstone, the Saint Lawrence formation, and the Jordan sandstone—were absent here either through nondeposition or pre-Ozarkian erosion" (Ulrich, 1916, p. 459).

Ulrich then discussed a second outcrop in a large quarry nearby. Here, there is an exposure of sandstone that Ulrich had previously thought to be Dresbachian (early Late Cambrian). After making this assessment, Ulrich had received a report during the winter that Franconian brachiopods had been collected from the exposure; that would indicate a middle Late Cambrian age for the rock. Ulrich hurried back to Wisconsin the next June to see for himself. Here is his description of the discovery:

> *The quarry in which the Franconia fossils had been found was the first to be visited. Its face exceeds 100 feet in height. The greater lower part of this quarry face, on close examination, again seemed to me surely Dresbach. Then it was learned that the fossiliferous bed is near the top of the quarry. . . . Just beneath the fossil bed a suspicious contact was observed, which, on being traced around the quarry, proved to be irregular and at one place very much so. Moreover, touching or lying on this uneven plane we found boulders of Baraboo quartzite, moderately rounded and up to five feet in diameter. Finally the sandstone for 10 to 15 feet above this contact was shown to be thinner-bedded and less silicified than is the more massive sandstone beneath it. Evidently the two belong to distinct formations. And thus we proved that an exposure of sandstone which until then had always been regarded as belonging to a single formation in reality contains adjoining parts of two unconformable formations (Ulrich, 1916, p. 459–460).*

Ulrich's discovery anticipated a major insight of modern sequence stratigraphy, that sequence boundaries can be cryptic, lying *within* apparently homogeneous lithologic units. For example, the top of a stratigraphic sequence (highstand systems tract) is likely to include shallow marine sandstone. The base of the overlying sequence (transgressive systems tract) may also consist of shallow water sandstone. The result is sand on sand, and the two units may be mapped lithostratigraphically as a single sandstone formation. The actual subaerial erosion surface separating the two sequences lies somewhere within the formation and may be hard to recognize. Ulrich had figured this out more than 80 years ago. Although he boasted in his 1916 article that it took him little more than an hour to find the unconformity, and his description makes it sound obvious, he points out in his conclusion that no one had ever noticed it before.

Unfortunately, Ulrich's miscorrelations, taxonomic oversplitting, and inability to recognize facies changes caused most of his stratigraphic work to fall into disrepute after the 1940s. Modern sequence stratigraphy was developed independently, beginning in the 1970s, and some of Ulrich's concepts have since been reinvented.

CONCLUSIONS

To review, near Rock Springs Ulrich saw two outcrops with erosion surfaces cut into the Dresbach Sandstone: At one locality the overlying sandstone contains abundant conglomerate and was interpreted to be Ozarkian in age. At the other locality, the overlying sandstone is less conglomeratic, but also contains Franconian fossils and was interpreted to be Cambrian.

In hindsight, it is clear that the erosion surface is the same one in both exposures. It is Cambrian, the contact separating the Wonewoc (Dresbach) from the overlying Tunnel City (Franconia). Because fossils were absent at one of the localities, Ulrich had no biostratigraphic evidence for the age of the erosion surface, and he relied on abundance of conglomerate instead. In this instance Ulrich was unable to match an unconformity correctly between two closely spaced outcrops. It is no mystery that he failed to get it right in correlating between Missouri and the Appalachians.

Sequence stratigraphers face exactly the same problem today. The standard Exxon sea-level curve shows scores of sea-level fluctuations, recurring on a scale of a million years or less. Given that the timing of sea-level change lies at or below the resolution of standard biostratigraphy and geochronometry, correlation by matching surfaces is open to the same errors made by Ulrich.

Andrew Miall pointed out the difficulty of correlation by unconformity-matching in his 1992 paper. Miall constructed four synthetic columns of unconformities using random numbers. He was able to match these randomly positioned surfaces to the Exxon column at a *minimum* of 77 percent of occurrences, using a resolution of plus-or-minus one million years. Miall's conclusion was that wherever one needs an unconformity for correlation, one will be available, but most likely it will be the wrong one. As the stratigraphic record is reinterpreted in the light of modern sequence stratigraphy, geologists need to be careful not to walk again down the path that Ulrich took.

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