

BASE OF THE RHAETIAN AND A CRITIQUE OF TRIASSIC CONODONT-BASED CHRONOSTRATIGRAPHY: COMMENT

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INTRODUCTION

Elsewhere in this volume, Spencer Lucas has argued for the “abandonment of conodonts as a tool for chronostratigraphic definition”, and a “return to ammonoids as primary signals”. He fails to explain or propose which ammonoids would be more suitable primary signals, but rather he supports this view by listing five disadvantages of the microfossil group, and by citing several cases where our knowledge of boundary conodonts has recently improved, which he claims renders them unreliable. On the contrary, conodonts are becoming ever more useful in the geological sciences, including Triassic biochronology, as I shall attempt to show here.

From the outset it needs to be stated that GSSP proposals are considered on their merits in terms of both the fossil record and the “non-unique” physical and chemical signals rejected outright by Lucas (Walsh et al., 2004). There is no a priori use of conodonts for this purpose, or any “movement” to towards doing so, they just happen to be extremely useful. In contrast to the alleged ‘tyranny of conodonts’, the last decade has, in fact, seen the choice of an ammonoid as a primary datum for the only two defined intra-Triassic GSSPs, the Anisian-Ladinian Boundary and the Ladinian-Carnian Boundary. The Permian-Triassic Boundary remains the only datum defined by a conodont. As Lucas writes, two other conodont datums have been proposed but these GSSPs have not been concluded pending clarification of some specific taxonomic and biostratigraphic issues, which are being addressed.

Of course, ammonoids do provide the essential historical framework for the present Triassic time scale: stage boundaries were broadly established by very visible (and sometimes mixed!) ammonoid fossils long before the advent of conodonts. The relative novelty of these microfossils cannot be denied, but nor can the tremendous progress that has been made. We now have a rather complete fossil record for the group through the Triassic, as in the Paleozoic where they have been studied longer, and where conodonts frequently serve as boundary indices. The conodont fossil record lends itself to phyletic and evolutionary studies much more than that of less resilient fossils. Calcareous fossils rarely enjoy this advantage, although they certainly provide some superb successions. Lucas’s facetious comment about “joining the dots” reveals an ignorance of how clearly displayed morphogenesis often is in the conodonts.

CONODONT-BASED CHRONOSTRATIGRAPHY

Lucas lists five diverse problems with conodont-based chronostratigraphy. I comment on each one below.

Taxonomic & stratigraphic instability

Yes, Triassic conodonts have been studied for only 50 years. During that time, our knowledge has gone through a revolution in terms of SEM micro-imagery and multielement taxonomy. Much remains to be done, but for which fossil group is that not the case? – Jurassic ammonite zonations have undergone constant revision since Opper developed the concept of a biostratigraphic zone 150 years ago! My perspective after 45 years of conodont research is that both conodont taxonomy and biostratigraphy has reached a solid level of maturity and stability. If progress is slow it is simply that there are too few conodont researchers working on boundary definitions. Lucas argues that recent taxonomic and stratigraphic revisionism render the group less useful, whereas I regard such work - which generally involves larger and denser sampling of key intervals - as taking us exactly where we need to be.

Reworking

In spite of examples cited by Mack & Nichols (2007) from often dated literature on Devonian-Mississippian lag deposits, the reworking phenomenon is uncommon in my experience. It is generally easy to recognize when it does occur, and resulting ‘derived’ data adds considerably to geological interpretations: e.g. recognition of ‘ghost stratigraphy’ and erosional history. Reworked conodonts are, like reworked zircons, obvious in lacking pristine ‘facets’ and are not selected to provide dates. In cases of extreme condensation, one must take great care of course – as is equally true of ammonoids: stratigraphic admixture and leakage of ammonoids in Alpine Hallstatt limestones originally led to far more erroneous chronostratigraphy than any cited by Lucas! (see historical review in Tozer, 1994).

In some clastic successions, e.g. the Triassic Liard Formation in B.C., rare eroded conodont elements are corroded and discoloured (and perhaps have a different Color Alteration Index) compared with contemporaneous elements. A more common reworking phenomenon is where coarse clastics contain clasts from which conodonts can be isolated, sometimes separately,

to reveal the source rocks. One may run into a problem only if the clast-bearing nature of the rock is not realized and a contemporaneous microfauna is absent. It should also be noted that conodonts are well enough known now to recognize admixtures of differing ages (contra Macke & Nichols, 2007).

Facies, provinciality

To portray conodonts as in some way uniquely deficient in this area is misleading. Non-paleontologists point to all fossils as sharing this drawback, and therefore insist on truly global, instantaneous events as integral to definition (Smith et al., 2014). We can point to the differing habitats occupied by all creatures, past and present, to demonstrate temporal lag in migration, or absence from some facies. We can be confident that active predators, like most conodonts and ammonoids, were more widespread than most, and became widespread rapidly. I see no merit in presenting either fossil group as in some way superior in this particular regard. Of course, when there is demonstrable facies dependency or paleobiogeographic partitioning, the conodonts (and other fossils) become a different kind of tool – very useful in basin and terrane analysis.

Invisibility

This is a moot point. I have spent much of my time in the field in the company of macropaleontologists and I am delighted when they are able to proclaim the age of strata on the spot! The late Tim Tozer guided me through Triassic successions for many years, and I was able to collect conodont samples that were tightly intercalibrated with his ammonoid zones (Orchard and Tozer, 1997). Furthermore, I collected samples from beds between his preserved ammonoid faunas, and in doing so I was able to delineate biozones in intervening strata. A more complete conodont succession and, consequently, a more refined chronology resulted, and this is often the scenario in integrated ammonoid - conodont stratigraphy. Obviously these advances can hardly be achieved in the field but require laboratory extraction. However, the issue is the value of conodonts in chronostratigraphy, not as an aid in field geology (but see Cordey & Krauss, 1990). It should be added that the careful preparation of macrofossils in the laboratory is often necessary prior to precise determination.

GSSPS OLD AND NEW

Lucas makes the point that a decade has passed since the 2007 Albuquerque meeting when the status of outstanding GSSPs was discussed, and he presents this as a further reason to abandon conodonts. He notes several examples of how conodont range has been modified, and criticizes some of the science that has been published as lacking rigour. With a single paragraph on each of several Triassic boundaries, Lucas offers the reader a stark summary of conodont shortcomings to date. His broad dismissal of conodonts demands a more thorough review of not only the problems that have emerged, and also the considerable progress made to address them as we move close to resolution of

the Triassic time scale.

Permian-Triassic Boundary (PTB)

Choice of the first Triassic GSSP resulted from a multidisciplinary study of all the then available data to identify a sequence of biological, physical, and chemical events at the erathem boundary (Yin et al., 2001). The well-studied Meishan succession incorporated many biotic and non-biotic signals, one of which, the first appearance of *Hindeodus parvus*, was selected as an index: this is a common and globally distributed conodont that occurs in a wide variety of facies.

The PTB has continued to receive intensive study in recent years. The chemostratigraphy is now much better understood, as is the conodont taxonomy. Numerous new species of the related *Hindeodus* and *Isarcicella* have been differentiated since the GSSP was defined (see Orchard, 2007 for list), and there have been taxonomic advancements in morphometric analysis of *H. parvus* morphotypes (Chen et al., 2009), and cladistical analysis of the entire *Hindeodus-Isarcicella* clade (Jiang et al., 2010, 2011). Refined conodont and carbon isotope data from more expanded sections than that at Meishan support the view that the appearance of *H. parvus* at the GSSP is younger than its appearance elsewhere (Jiang et al., 2011; Brosse et al. 2015; Zhang et al., 2014; Yuan et al., 2015). This progress arises directly from the refinement of conodont biostratigraphy which has proven to be self-correcting as more intensive studies focused on the boundary interval. The facts may represent a shortfall for the relatively condensed type section at Meishan with its dissolution phenomena (Chen et al., 2009), but not for *H. parvus* as a correlative tool and useful index.

Induan-Olenekian Boundary (IOB)

As shown by Goudemand (2014), new fossil collections from Mud, Waili, Chaohu, and Nammal Gorge enable further taxonomic revision of the *Neospathodus waageni* group and have resulted in both a consistent conodont succession, and a tighter calibration with ammonoid faunas. Although unpublished in detail, this work continues the modern revisionism of the conodont group that dates from a decade earlier (Zhao et al., 2004). More thorough sampling of the Mud section, supplemented by new data from Chinese and Pakistan sections, yielded and replicated new conodont taxa within the waageni group (Goudemand, 2014). The decision to define the IOB on the appearance of this species spectrum, characterized as *N. ex gr. waageni*, was not without merit even if it was, in retrospect, premature and imprecise. As Goudemand states, the newly differentiated conodonts “can be used to define the base of the IOB”, and are fully consistent with the ammonoid data.

Olenekian-Anisian Boundary (OAB)

The story of the OAB revolves around *Chiosella timorensis*, a common species in lower Anisian strata worldwide. For example, it is common in the *Japonites welteri* beds in Nevada (Orchard, 1994), and more recently was found to be abundant in the early Anisian of Deşli Caira, Romania (Orchard, Grădinaru et al., 2007); its common occurrence in Guandao, China lacks

independent fossil control but the succession of conodont taxa is the same as in Romania (Orchard, Lehrmann, et al., 2007). On the basis of its consistent occurrence and age, it was proposed as an index for the OAB at Deşli Caira, where it is very well aligned with the other fossil elements (Grădinaru et al., 2007). This proposal was initially supported by the fact that conodont samples from the late Spathian *Haugi* Zone of Nevada (mostly collected and identified by Hugo Bucher) failed to produce a single specimen of *C. timorensis* until very recently when a single float sample did so (Goudemand et al., 2012). So, we now know that – in terms of ammonoid stratigraphy – the conodont species straddles the traditional ammonoid boundary; it remains to be seen if this is true at Deşli Caira, where we have long awaited a full account of the ammonoid succession and its correlation with Nevada.

Tentatively, the *Haugi* Zone may be divisible into lower and upper parts based on the presence of *C. timorensis* and, setting aside ‘tradition’, the conodont could be used as an index to the OAB and some part of the *Haugi* Zone may be assigned to the Anisian! (anathema to ammonoid workers no doubt!). That is not something I am advocating, but the main point to make is that *C. timorensis* remains an important guide fossil to recognize, if not define the base of the OAB. Other conodont taxa, some new, were reported by Orchard et al. (op. cit.) from both Romania and China in studies intended to stabilize the taxonomy around the OAB. Using this taxonomic base, Ovtcharova et al. (2015) recently recast the conodont data from Romania and China and compared new data from China. Through the application of Unitary Association they recognize two laterally reproducible maximal associations/ conodont biozones between which the ‘traditional’ OAB falls. They conclude that, with adequate sampling, there is no detectable diachronism in the first occurrence “of a nektonic or a pelagic species”; good news for both conodonts and ammonoids. The conodonts of the OAB provide excellent characterization of the boundary interval and in conjunction with other criteria can provide an appropriate GSSP definition.

Carnian-Norian Boundary (CNB)

This boundary was the subject of a recent monograph on conodonts from the CNB GSSP prospect at Black Bear Ridge (BBR) in British Columbia. As Lucas notes, many new taxa are described in this work, which largely reflects the relative novelty of the rich and partly endemic North American tropical fauna. The work was also designed to provide the taxonomic basis for a thorough comparison with Tethyan taxa, an advance made possible through lavish illustration in Lucas’s museum publication series! Cosmopolitan species also occur at BBR and these were used by Orchard (2014) as a basis for correlations with Pizzo Mondello, an alternate Sicilian candidate. The contemporaneous conodonts from the latter area (Mazza et al., 2012) are presently less differentiated, and also partly endemic, but the two GSSP candidate sections can be correlated with both conodonts and carbon isotopes anomalies. Both ammonoid and bivalve faunas in these sections provide broad age constraints but are less useful than the conodonts in providing bed-by-bed correlation, or chronomorphoclines (see Orchard, 2014, fig. 30).

Norian-Rhaetian Boundary (NRB)

The *Misikella* chronomorphocline that features in current proposals for the NRB involves the development of an indentation/ re-entrant in the posterior margin of the P1 element in stratigraphically younger elements. This morphogenesis is seen in many sections worldwide. Lucas (this volume) criticizes the work by Giordano et al. (2010) as providing incomplete documentation of this morphogenesis, although that does not make it any less real. Lucas suggests that the re-illustrated *Misikella* chronomorphocline is flawed, and suggests that elements illustrated as figs. 4 and 6 are morphologically closer than figs. 5 and 6. I see no basis for such a suggestion: the re-entrant can be seen to develop progressively through the illustrated elements. I believe Krystyn et al. (2007a, b), well understood this, and the limitations of using alternative ammonoid indices in their proposal for the NRB. There appears to be no superior ammonoid index option for the NRB, and nor does Lucas suggest one. His urging “for conodont micropaleontologists to document their chronomorphoclines ... more rigorously” is not without merit, but to imply this is not an issue for ammonoid researchers to address for their group (around any Triassic boundary) leaves much unsaid! The first appearance of *M. posthernsteini* needs to be resolved, as does correlation with North America, where *Misikella* is rare (but see Orchard, Whalen, et al., 2007; Orchard, Carter, et al., 2007).

SUMMARY

Conodonts are a valuable tool for application in stratigraphical, paleoenvironmental, and other geological problems. Their role in biochronology has become increasingly important and they will continue to be an essential ingredient, if not a primary signal, for all Triassic GSSPs. The choice of definition requires an assessment of ALL available criteria and the choice of a single datum needs to be set in the context of a replicable succession of events. To suggest that conodonts cannot be reliably factored into such deliberations, or serve as primary indices, is nonsense.

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BASE OF THE RHAETIAN AND A CRITIQUE OF TRIASSIC CONODONT-BASED CHRONOSTRATIGRAPHY: REPLY

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My article emphasizes recent and current problems in using conodonts for Triassic chronostratigraphic definitions. I concluded that Triassic conodont stratigraphic ranges are so poorly established and their taxonomy is so new and unstable that they are hindering, not helping definition of a Triassic chronostratigraphic scale. Not surprisingly, Mike Orchard, who has devoted much of his career to developing Triassic conodont biostratigraphy and chronostratigraphy, disagrees with me. Yet, much of Orchard's text explaining the disagreement reiterates (in greater detail than did I) the reasons why Triassic chronostratigraphic boundary definition based on conodont biostratigraphy is a shambles. Thus, he concedes that *Hindeodus parvus* is diachronous, so that its LO (lowest occurrence) at the Meishan GSSP is younger than some other records; he concludes that the recent attempt to use *Neospathodus waageni* as the primary signal of a base Olenekian GSSP was "premature and imprecise;" he explains that *Chiosella timorensis* cannot be a primary signal for an Anisian base unless that base is move downward to capture recent range extension of that species into Spathian strata; he acknowledges that his recent publications on a possible base Norian GSSP in western Canada introduced very many new conodont taxa; and Orchard concedes that "the first appearance of *Misikella posthernsteini* needs to be resolved" to use it to define a Rhaetian base.

I agree with Orchard that what we have been learning about Triassic conodonts during the last decade is progress. Indeed, this progress demonstrates how poorly established are the stratigraphic ranges of many Triassic conodont species, and how many new Triassic conodont taxa remain to be found/identified. Furthermore, this progress should lead us to realize that there has been little to no progress on many chronostratigraphic definitions of the Triassic timescale because whenever somebody proposes a conodont taxon LO as the primary signal of a Triassic GSSP, we soon find that conodont taxon in older strata or its taxonomy is revealed to be in need of an overhaul.

Orchard also agrees with me that Triassic conodont taxonomy is young, that conodonts can be reworked, that they are subject to restriction by facies and provinciality and that conodonts are invisible on outcrop. That is good, because it means that conodonts have all the problems we face with other fossils used in biostratigraphy, and more—nobody can see them on outcrop, so they are of no use to geologists in field studies. Orchard concludes that "my perspective after 45 years of conodont research is that both conodont taxonomy and biostratigraphy has reached a solid level of maturity and stability." Yet, most of the rest of his text (as stressed above) contradicts that conclusion by recounting stratigraphic range extensions and taxonomic changes/new taxa that have pervaded the study of Triassic conodonts during the last decade.

Orchard is not bothered by undocumented conodont chromomorphoclines such as the chromomorphocline of *Misikella hernsteini* to *M. posthernsteini* presented by Giordano et al. (2010) because he somehow "knows" they are real. His point of view on this well represents what I called the "corporate culture" of conodont micropaleontologists, which is to produce chromomorphoclines akin to "connect-the-dots art," instead of the rigorously and metrically documented chromomorphoclines proposed in evolutionary studies of other taxonomic groups. Again, I urge conodont micropaleontologists to document their conodont chromomorphoclines more extensively and more rigorously before they are considered for use in chronostratigraphy.

The Triassic timescale was built on ammonoid biostratigraphy. I have, very explicitly, pointed out one way forward using ammonoids to define all Triassic chronostratigraphic boundaries (Lucas, 2013). I agree with Orchard that conodonts are valuable to the development of a Triassic timescale as one of several tools by which we correlate Triassic strata. But, if we continue to propose Triassic GSSPs for which conodonts are the primary signal, then we will continue to see those primary signals fail.