Arriving at an Induan-Olenekian Boundary GSSP

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HISTORICAL CONSIDERATIONS

The modern International Geologic Time Scale recognizes two stages in the Lower Triassic (Ogg, 2012), the Induan and Olenekian, but many workers continue to use as substages, the informal stages Griesbachian, Dienerian, Smithian and Spathian as originally determined in Arctic Canada. Both sets of terminology are used here, with the Induan essentially equal to the Griesbachian and Dienerian, and the Olenekian more-or-less equal to the Smithian and Spathian. The base of the Smithian was originally defined in the Blind Fiord Formation at Smith Creek on Ellesmere Island at the Romunderi Zone above the Sverdrupi Zone (Tozer, 1967) and later at the base of the Hedenstroemi Zone on the basis of occurences elsewhere (Tozer, 1994). ICS is not currently planning to formalize substages, so the task of the IOBWG should be simple – pick a point and a section to define the Induan–Olenekian boundary (=base-0lenekian GSSP).

GSSP CONSIDERATIONS

A majority of current GSSPs use biostratigraphic data as the primary marker, but it is critical that other physico-chemical markers should be referenced as secondary markers to facilitate the development of a high-precision time scale (Smith *et al.*, 2014). In so doing, we recognize that *correlation precedes definition* as a basic tenet of the process. The FAD of a species (if chosen as primary marker) defines a stage boundary only at the GSSP section, everywhere else we are trying to correlate. It is likely that the defining species will be missing in some sections (especially non-marine) and in other sections the FO will be (hopefully) younger than the FAD. Therefore correlatability is only achieved when as many secondary markers as possible, especially those that are recorded in both marine and terrestrial realms, are included in the definition. Demonstrating correlation of different geologic and bioevents in numerous widely distributed sections will show the event that is most useful for global correlation and ultimately point to the best section for definition. It is the goal of the IOBWG to reach a consensus (at least 60% majority) and submit a report to STS. If voting members vote 60% in favour it is passed on to ICS for a similar vote and ultimately to IUGS for formal acceptance. It is important to note that chronostratigraphic studies do not terminate with formal acceptance of a stage boundary, but rather continue within a defined temporal framework. These additional studies could continue to test the correlatability or focus on rates of evolution, migration, climate change, sea level and deposition between globally defined points. Furthermore, a formally accepted international stage does not replace regional stages or informal substages, but rather provides a formal chronostratigraphic framework for comparison.

SEQUENCE STRATIGRAPHY

Rocks deposited during the 4.8 million years of the Early Triassic (Ogg, 2012) are globally subdivided into 3 third-order depositional sequences (Embry, 1997). The first more or less equals the Induan (Griesbachian and Dienerian), the second approximates the lower Olenekian (Smithian) and the third approximates the upper Olenekian (Spathian). Original stage and system boundaries were often recognized at sequence boundaries because differences in biota and depositional setting were clear across the time gap. A GSSP must be defined in an interval of continuous deposition with little facies variation and therefore must occur below or above a sequence boundary or its correlative maximum regressive surface. The IOBWG has been focusing on a base-Olenekian definition within the transgressive part of the second Lower Triassic depositional sequence. It is possible that some people may object that part of what is currently called Smithian will be included in the Induan, but we should remember that this is the consequence of defining a point within a continuous succession and furthermore, the base of the Smithian has not been formally defined.

CONODONT EVOLUTION AND TAXONOMY

The early Olenekian (Smithian) is a time of evolutionary radiation in conodonts (Orchard, 2007; Orchard & Zonneveld, 2009) as well as ammonoids (begins in late Induan, i.e. Dienerian; see Ware et al., 2015) in which there is a significant increase in diversity. The conodont diversity can be interpreted in different ways depending on taxonomic approaches, which can be classically subdivided into the 'splitters' and the 'lumpers'. The result is either a large number of formal taxa or populations with high variability; it is possible to capture some of that variability with a number of morphotypes of a taxon. Regardless, during such times, the morphologic plasticity is high and this represents both a problem and an advantage. The problem is that others in the Triassic community might interpret that conodont work is still early in development and that specialists cannot decide. The advantage, however, is that conodonts offer a great deal of potential resolution during these intervals. My research suggests that this morphologic plasticity is greatest in the "centre of evolution" and that at the extreme ranges of distribution only certain morphotypes occur – it is as if evolution is complete when certain species or forms migrate away from the centre. This would suggest that picking a point within or near the end of the major radiation stage would have greater correlation potential compared to a point at the beginning of this radiation.

PERSONAL RECOMMENDATION

The IOBWG has made progress over 20 years and has essentially adopted the position of the FO of *Novispathodus waageni sensu lato*. In practice, this has already worked very well in many sections of the world including the proposed GSSP localities (Goudemand, 2014). I am open to other potential points, but my inclination is to pick a formal, perhaps arbitrary point within the broad sense of *Nv. waageni*. This level or point should be chosen as the one with the greatest potential for correlation by incorporating all other available tools including, but not necessarily limited to, magnetostratigraphy, chemostratigraphy (carbon isotopes), other fossils, geochronology, cyclostratigraphy (Li et al., 2016), and sequence stratigraphy. It is important that all of this work be fully integrated into our definition. Only then should we decide the section that best expresses this correlation, as well as being accessible; secondary reference sections are permissible. Currently, we have three sections on the table including 1) the Mud section (Spiti, Himashal Pradesh) M04 in northern India (Krystyn et al., 2007a, b), 2) West Pingdingshan section at Chaohu in Anhui Province, South China (Tong et al., 2003, 2004), and 3) the Nammal Gorge section in Pakistan (Romano et al., 2013). In the end, our recommendation to STS should read something like "we propose that the base-Olenekian GSSP is defined by the FAD of *Nv. decidedus* (i.e. we have decided) at 100x metres in a particular section, and a major carbon isotope shift, and/or certain magnetic reversal, and/or the appearance or disappearance of other fossils, which must at least include ammonoids, serve as secondary markers to correlate this point".

ACRONYMS

IOBWG: Induan-Olenekian Boundary Working Group
STS: Subcommission on Triassic Stratigraphy
ICS: International Commission on Stratigraphy
IUGS: International Union of Geological Sciences
GSSP: Global Stratigraphic Section and Point is the material reference for the stage boundary definition, but it is useful only when it can be correlated widely by as many means as possible.
FO: the local first occurrence of a taxon in any given section, which collectively will likely be diachronous
FAD: the true first occurrence or evolution of a taxon representing its First Appearance Datum; usually determined, within resolution limits, only when compared to synchronous events like, for example, an isotopic shift or magnetic reversal. The definition of a stage boundary does not necessarily have to change if a FO is later shown to precede an identified FAD because the stage boundary is correlated with as many chronostratigraphic tools as possible.

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Correlating the Induan-Olenekian Boundary GSSP

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INTRODUCTION

A potential way to consider correlation of a base-Olenekian GSSP is to first consider the sequence stratigraphy in various sections. Assuming 1) the base-Olenekian GSSP should be located above a sequence boundary (SB) and at or above the equivalent correlative conformity or maximum regressive surface (MRS), and 2) that these surfaces can be reliably identified, then we have a reasonable way to compare the ranges of various taxa.

WESTERN AND ARCTIC CANADA

Baud et al. (2008) showed a co-planar SB and flooding surface in the Blind Fiord Formation with *Novispathodus waageni* above and *Euflemingites romunderi* just a little higher. The exact same occurrences are found above a SB at Opal Creek in SW Alberta. In west-central Alberta there is a SB within a coquina unit and a major flooding surface a little higher that includes *Novispathodus waageni*. In east-central British Columbia Orchard and Zonneveld (2009) showed a section which appears to be conformable with a turbidite unit (Meosin Mountain Mbr) a little higher. Immediately overlying this MRS the conodonts *Nv. waageni* and *Nv. latiformis* co-occur with *Discretella discreta* and *Euflemingites* is a little higher.

OTHER SECTIONS

The sequence stratigraphically significant surface discussed above is interpreted by me at the Mud (bed 13A), Chaohu (bed 25-18), and Nammal Gorge (near top of Ceratite Sandstone) sections that represent potential GSSPs. Using this surface as a datum suggests that above the surface some Nv. waageni morphotypes including *Nv. latiformis* occur with *Flemingites nanus* at Mud (Krystyn et al., 2007a, b). Similar taxa occur above this surface at Chaohu including Eurygnathodus costatus (Tong et al., 2004), but *Flemingites* and *Euflemingites* are just below. The latter may be a good secondary marker in tethyan faunas. The top of the Ceratite Sandstone was the original top of the Induan. According to Romano et al. (2013), *Fleminites nanus*, *F. bhargavai*, and *Nv. waageni* occur below the surface and *Euflemingites*, *Nv. waageni* and *Nv. spitiensis* occur above.

CONCLUSION

There are some issues with my seemingly simple initial correlation of a SB/MRS surface in terms of biotic occurrences on either side, but overall there is a close correspondence that suggests correlation is likely, especially as new details emerge from the workshop. In addition, other physico-chemical markers need to be considered before a GSSP can be determined.

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