VOLUMINA JURASSICA, 2017, XV: 181–186
DOI: 10.5604/01.3001.0010.7467

# Developments with fixing a Tithonian/Berriasian (J/K) boundary

William A.P. WIMBLEDON[1]
Chairman, Berriasian Working Group (ISCS)

At the Vienna Cretaceous Symposium (August 2017), the Berriasian Working Group (International Subcommission on Cretaceous Stratigraphy) gave an account of its concerted research activities since 2009 (Wimbledon *et al.*, 2017) – that and this text are abbreviated summaries of Tithonian–Berriasian studies carried out in preparation for the consideration and choice of a GSSP. Past decisions have consistently stated that such a GSSP should be defined in Tethys. Of Panthalassa, only a comparatively small area of Lower Cretaceous ocean floor survives (NW Pacific), and subduction effected similar losses in the Arctic, and thus parts of tropical-subtropical Tethys constitute the largest geographical entity remaining from J/K times, and the one with the richest, most widespread and most studied biota.

In the 1970s to 1990s, discussions in various working groups about a J/K boundary made no substantive progress (Remane, 1991), and were suspended until more auspicious times came. By the early 2000s, J/K correlation had already shifted away from a concentration on often endemic ammonites, which had repeatedly been recognised as a major obstacle to correlation, even in western Tethys. In 2007, a new Berriasian Working Group (ISCS) was mooted and it initiated a new phase of activity, concentrating on realities and refining Tithonian–Berriasian correlations, partly directed at fixing a J/K boundary. For this reason, the preoccupations of the earlier Cretaceous symposia and earlier working groups, dominated by ammonite discussion, have been put aside and since 2009 work has refocussed on integrated high-resolution studies, including ammonites, but more on the effective use of several microfossil groups (*e.g.* calpionellids, calcareous nannofossils, calcareous dinoflagellates), which give greater precision, calibrated with magnetostratigraphy. The J/K interval is without any marked chemostratigraphic event that can help us in fixing a boundary, isotopic excursions are lacking (Price *et al.*, 2016), and thus correlative methods must be predominantly biostratigraphic and magnetostratigraphic. The WG has focussed on the detailed documentation of numerous key profiles, old and new, putative J/K levels, calibrating magnetostratigraphy with fossil range data, and examining prospective primary marker levels formerly suggested: *e.g.* the bases of the Jacobi Subzone, the calpionellid Alpina Subzone, of M18r, and the Grandis Subzone. Many localities, from California to Tibet and the Russian Far East, have been documented and assessed, including classical localities in France, Crimea, *etc*. Of course, long-range correlations to some remote boreal regions, with impoverished, endemic biotas (*vis a vis* Tethys), as well as the extensive non-marine basins, remain approximate. Though much work has recently been put into the magnetostratigraphy of the Purbeck Formation in England.

Documentation of classical Berriasian areas has led to some significant revisions: we have highlighted the absence of '*Berriasella' jacobi* in the lower part of the nominal Jacobi Subzone (Frau *et al.*, 2016), and the predominance of *Delphinella* (*e.g.* France and Ukraine): thus *Strambergella jacobi* (and the Jacobi Subzone) has been ruled out as a GSSP marker. Continuing problems with separating the ammonite assemblages of the Jacobi and Grandis subzones of past authors have meant that we have not pursued the Grandis Subzone's base as a putative stage base (Fig. 1). Better resolution also has shown that the base of the Alpina (calpionellid) Subzone and the Jacobi (ammonite) Subzone do not coincide, and the Elliptica Subzone base is below that of the Occitanica Zone.

[1] School of Earth Sciences, University of Bristol, U.K.; mishenka1@yahoo.co.uk.

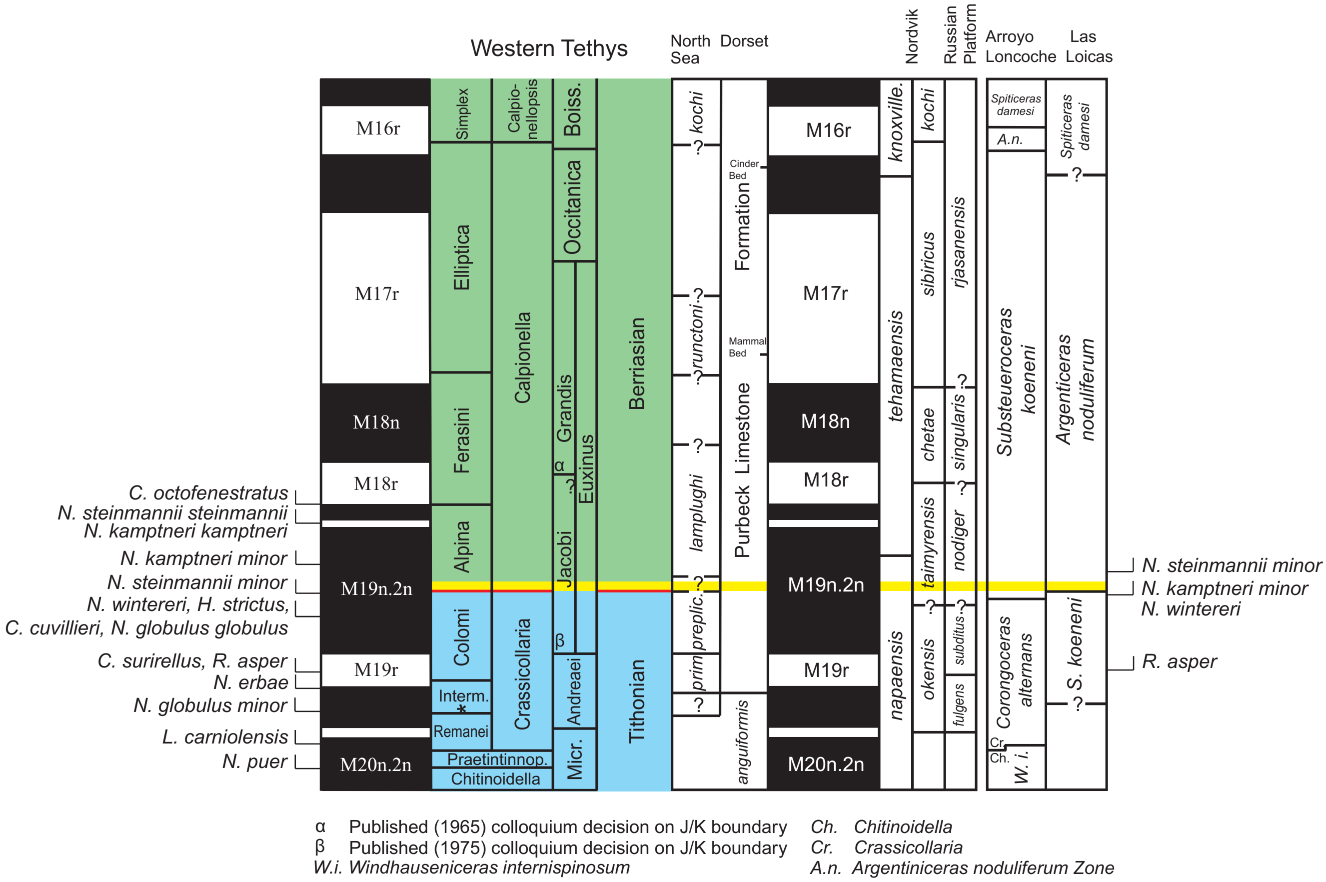

Fig. 1. Correlations of Tethys with austral and boreal regions

Another boundary alternative put forward in the past, the base of magnetozone M18r, has not proved to be effective as a J/K marker. It is widely identified, of course, but it cannot be calibrated with any widespread fossil marker: its proposal (*e.g.* Arkadi'ev *et al.*, 2017) has not been supported by any documentation of biotic events (calpionellid, ammonite or nannofossil) at, or bracketing the base of M18r.

For the last twenty years, building on a considerable and growing body of literature. calpionellids have been seen by numerous authors as the most useful fossil group that could provide a J/K marker. Further, the turnover from *Crassicollaria* and large *Calpionella* to small orbicular *Calpionella alpina* (together with *Crassicollaria parvula* and *Tintinopsella carpathica*) has been documented repeatedly as the most consistent and widespread marker in the middle of magnetic subzone M19n.2n, as recognised by the clear consensus amongst specialists at the Warsaw J/K workshop (Wimbledon, 2013). Work then in progress has since come to fruition and the Alpina level has been proven further east in Tethys, to Arabia and Iran, and west into the Americas (North and South). In June 2016, a formal ballot of the Berriasian WG led to a decisive vote that selected the Alpina Subzone base as the primary T/B boundary marker.

The FADs of calcareous nannofossil species are helpful indicators of the base of Alpina Subzone, as they bracket this level. But their ranges have been modified significantly due to recent research (Fig. 2), undermining the 1980s biozonation of Bralower. However, records of the FAD of *Hexalithus strictus* [=*H. geometricus*] have a restricted vertical distribution, straddling the base of the Alpina Subzone in 19n.2n. The FAD of *Nannoconus steinmannii minor* occurs in mid M19n.2n: immediately above the Alpina Subzone base (Puerto Escaño) or just below it (Rio Argos). *Cruciellipsis cuvillieri, N. wintereri* and *N. globulus globulus* occur a little lower, though at Puerto Escaño the FAD of the first species, unusually, is low in M19n.2n. The FAD of *N. wintereri* occurs just below the Alpina Subzone's base (*e.g.* Le Chouet, Puerto Escaño). *Nannoconus kamptneri minor* has latterly been recorded as first appearing in the upper half of M19n, *e.g.* at Theodosia, Puerto Escaño and Le

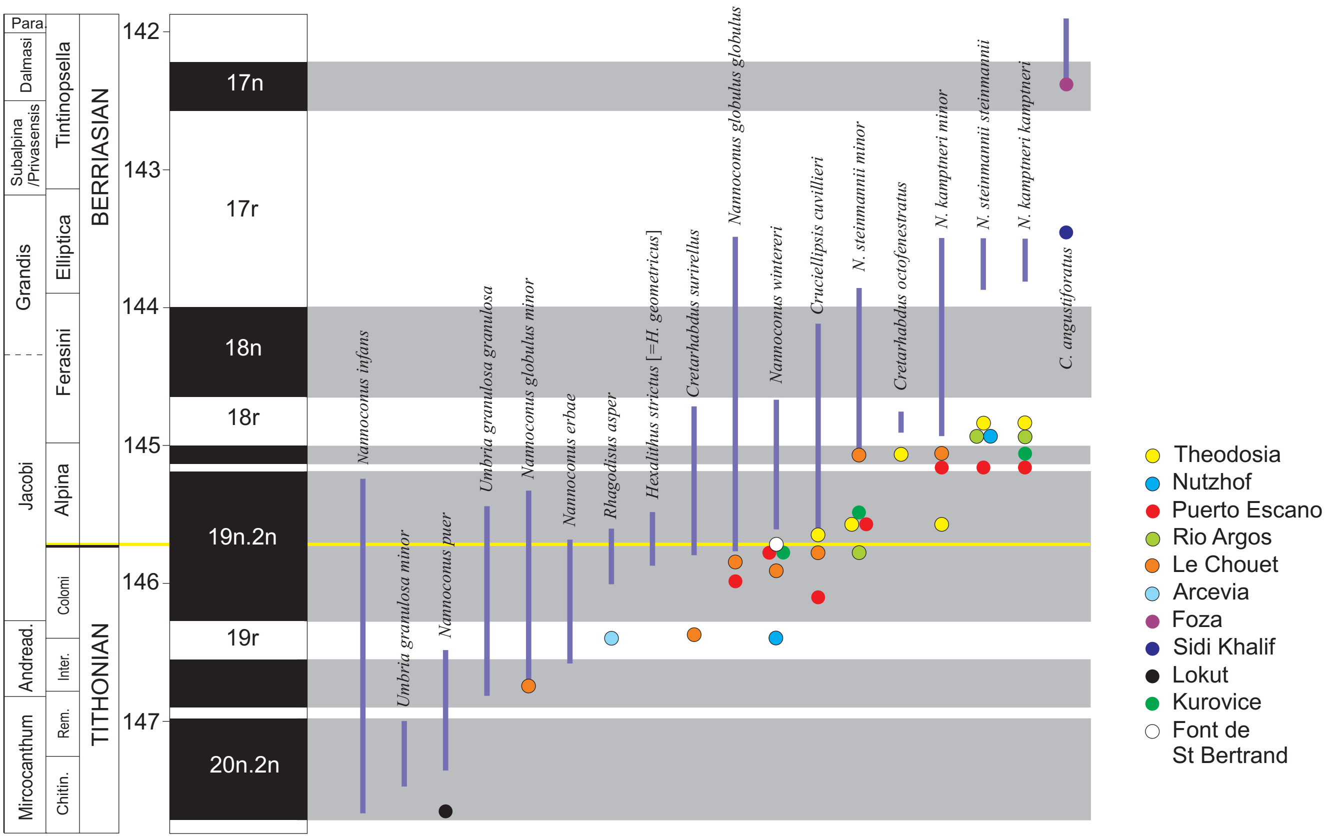


**Fig. 2. FADS of selected calcareous nannofossils in the Upper Tithonian to Lower Berriasian, calibrated with magnetozones and calpionellid biozones (modified from Wimbledon, 2016, Wimbledon *et al.*, 2017, Bakhmutov *et al.*, in press)**

Continuous vertical lines shows the distribution of FADS, in publications up to 2009 (after Casellato, 2010). Coloured spots represent records of FADS at lower stratigraphic levels (After Speranza *et al.*, 2005; Lukeneder *et al.*, 2010; Casellato, 2010; Wimbledon *et al.*, 2013; Hoedemaeker *et al.*, 2016: Svobodova, Kostak, 2016; Grabowski *et al.*, 2017; Švábenická *et al.*, 2017; Bakhmutov *et al.*, 2018, in press; Ebra *et al.*, 2018, in press; Gardin, unpublished). NB: At Le Chouet, magnetic subzone M19n.1r was not detected, so although *N. steinmannii minor* and *N. kamptneri minor* are shown in M19n.1n, their FADs may fall in M19n.2n. The record of *N. wintereri* in M19r at Nutzhof is currently being re-examined

Chouet. Even more striking, *N. kamptneri kamptneri* and *N. steinmannii steinmannii*, previously used as infallible biozonal indicators in M17r, have been found widely in lower M18r and the upper half of M19n (Figs. 1, 2)

In recent times, the western Tethyan core area with definite and precise microfossil correlations has been considerably expanded. In particular, there have been finds of Lower Berriasian nannofossil markers in N. Africa, Ukraine, Yemen, Iraq, Tibet and the Andes, *C. alpina* records in the Middle East and the Andes, the unambiguous application of the “western Tethyan” calpionellid scheme to Mexico (Lopez Martinez *et al.*, 2013), Arabia (Celestino *et al.*, 2016), northern Iraq (Wimbledon *et al.*, 2016) and Iran (Benzaggagh *et al.*, 2012), and magnetostratigraphic studies extended to California, the Andes and N. Africa for the first time. Definite calpionellid records in Australia, Papua and New Guinea *etc.* await fuller investigation, as do problematic nannofossils and radiometric dates (Liu *et al.*, 2013) in southern Tibet.

Interesting recent unpublished results from Fiume Bosso and Puerto Escaño reveal the calpionellid Ferasini Subzone has its base in M19n.2n, with, consequently, a more thinly developed Alpina Subzone. Which perhaps raises questions about the accuracy of earlier results for the Ferasini Subzone at these and other sites, and discrimination between M19n.1r and M18r in previous accounts.

Failed attempts at identifying calpionellids in the Andean sequences were related by Remane, but critical first finds by Fernandez Carmona and Riccardi (1998, 1999) have given impetus to a breakthrough, with identification of the Chitinoidella Zone (Kietzmann *et al.*, 2011) and the Crassicollaria Zone in the *Corongoceras alternans* biozone (Kietzmann, 2017). Though putative nannofossil proxies for the base of the Alpina Subzone (thus *circa* mid M19n) were recorded at Las Loicas (Vennari *et al.*, 2014), close to the base of the *Argentiniceras noduliferum* Zone, no *Calpionella* was found. Palaeomagnetic results from Las Loicas are still awaiting publication, but those from Arroyo Lonconche (Llanos *et al.*, 2017) are intriguing, as they put the Noduliferum Zone base not in magnetozone M19n, but higher, in M16r. At Las Loicas, Lopez Martinez *et al.* (2017) have since identified an assemblage with predominant small globular *Calpionella alpina* (albeit co-occurring with *Crassicollaria brevis*, *C. remanei* and *C. massutiniana*) and the Alpina Subzone at the base of the Noduliferum Zone (Fig. 1). All this makes it an exciting time for Tethyan: Andean correlations.

Work must now focus on expanding efforts to identify proxies for the *C. alpina* level in the more problematic regions. For instance, the application of belemnites in Siberia and the Pacific (Dzyuba, 2012). It seems that the comparatively little studied Siberian boreal areas, though with disappointingly poor preservation of significant nannofossil taxa (Zanin *et al.*, 2012) and a discontinuous record of endemic ammonites near the boundary (Schnabl *et al.*, 2015) (Fig. 1), still have considerable correlation potential with other fossil groups, and they need better (and much more) targeting of new localities for magnetostratigraphic study. In this context, Vishnevskaya (2017) records calcareous dinoflagellates in Siberia (*Stomiosphaerina proxima*, *Colomisphaera tenuis*, *C. lapidosa*, and *C.? fortis)* with radiolarians in the presumed Berriasian Bazhenovo Formation. This demands more research, as, if confirmed, they would be of use as proxies for calpionellids.

Calcareous dinoflagellate cysts are common fossils in the Tithonian to Berriasian of European and North African Tethys. They appear to have much potential as accessories to the calpionellids, though there are rather few recent accounts and the stratigraphic ranges of some species has yet to become static (*e.g. Stomiosphaera moluccana* and *Colomisphaera pieniensis*: Wimbledon *et al.*, 2013; and below). But of notably useful species, in the Balkans, the first appearance of *S. proxima* has been recorded in the upper Crassicollaria Zone, and said to have its FAD at the base of the Colomi Subzone, though it appears first in the Remanei Subzone in SE France. This restriction to the Crassicollaria Zone was emphasized by Rehakova (2000) (see also Lukeneder *et al.*, 2010: but note Lopez *et al.*, 2013).

*C. fortis* only just pre-dates *S. proxima* (appearing pre-Crassicollaria Zone), and its range straddles the upper Crassicollaria and Calpionella zones, affording a wider stratigraphic bracket: this proves to be the case in some French sites (*e.g.* Tre Maroua and St Bertrand). If such occurrences could be confirmed and consistently proved in Siberia (and perhaps the Russian Platform), it would be a step forward in accuracy in trying to correlate with the Crassicollaria/Calpionella zonal boundary. Vishnevskaya's FAD of *C.? fortis* in Siberia appears to be very high (Analogus Zone) and that of *S. proxima* is shown lower than one should expect (Exoticus Zone, ?M20n) as compared to Tethys, when the Alpina J/K boundary (M19n.2n) has been correlated with the Siberian Taimyrensis Zone. However, the original assignment of magnetozones numbers in Siberia, at Nordvik, may merit reconsideration. The reversed intervals, identified as M19n.1r, M18r and M17r, are of limited, and similar, thickness (Schnabl *et al.*, 2015). With a fresh mind and no preconceptions, perhaps one might reconsider the original magnetozone notation of Houša *et al.* and assign different numbers. That being as it may, more research on calcareous dinoflagellates is an absolute priority in boreal regions.

Most recently, Ivanova and Kietzmann (2017) record dinoflagellate cysts in the Andes: *Colomisphaera tenuis*, *C. fortis*, *S. proxima* (lower Noduliferum Zone) and *S. wanneri* (upper Noduliferum Zone). The *S. wanneri* biozone (Arroyo Loncoche) they characterise as Upper Berriasian (Noduliferum to Damesii zones). *S. wanneri* has been found higher in the Berriasian in the Carpathians, but it has also been collected in the Lower Berriasian in southern Ukraine (Bakhmutov *et al.*, 2018, in press), and it seems that it appears similarly early in France (Font de St Bertrand – Elliptica Subzone: Tre Maroua – Simplex Subzone), as does *C. vogleri* (Simplex Subzone). Kietzmann and Llanos (2017), discussing the results of Lopez Martinez *et al.* (2017), would correlate *S. wanneri* and *S. proxima* with the European Berriasian, as above, and have *Nannoconus steinmannii steinmannii* in the Andes indicate correlation with M17r in Tethys: but see Fig. 2.

## CONCLUSIONS

- No fossil species has anything like a global distribution in the Tithonian-Berriasian interval. Though *Calpionella alpina* is the most widespread.
- The base of M18r does not coincide with any consistent biotic marker at sites recently studied for magnetostratigraphy, and the same is true of the base of M19n.2n.
- The traditional Berriasella jacobi Subzone will play no part in any definition of the base of the Berriasian, nor can the species *Berriasella jacobi* [=*Strambergella jacobi*].
- Calpionellids (calibrated with magnetostratigraphy) provide the most effective primary J/K boundary marker, the *Crassicollaria* to *Calpionella* turnover, *i.e.* the Colomi/Alpina subzone boundary as shown in Figs 1, 2.

- In June 2016, the Berriasian Working Group voted, by a large majority (76%), to adopt the *Crassicollaria/Calpionella* turnover and base of the Alpina Subzone as the primary marker for the base of the Berriasian Stage: the WG now focusses on identification of the best candidate site for a GSSP.
- This level is bracketed by a number of nannofossil FADs (Fig 2).
- Correlative advances in Argentina are exciting, and amplification of the first palaeomagnetic results and of recent *C. alpina* finds are anticipated.
- In austral regions, most notably in the Andes, some of the Tethyan nannofossil marker species have been identified (alongside endemic ammonites), including species which are proxies for the base of the Alpina Subzone, as they have in Tibet.
- New finds of Tethyan calcareous dinoflagellate cysts in the Andes indicate their usefulness and potential as secondary markers.
- In Siberia, at one site, Nordvik, it is possible to approximate the horizon of *Calpionella alpina* (in mid M19n.2n): close below the base of the Tehamaensis (belemnite) Zone and close above the 'floating' Taimyrensis (ammonite) zonal base. Earlier finds of calcareous nannofossils in Siberia have yet to be followed up. Identifications there of calcareous dinoflagellates have great potential, and it is to be hoped they will provide proxies for calpionellid datums, as in austral regions.

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