

FIXING A BASAL BERRIASIAN AND JURASSIC/CRETACEOUS (J/K) BOUNDARY – IS THERE PERHAPS SOME LIGHT AT THE END OF THE TUNNEL?

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Abstract. Our tentative proposal is that several biological markers have potential to help define any putative boundary in the traditional basal Berriasian interval. That is, between the base of the Berriasella jacobi Subzone and the base of the Pseudosubplanites grandis Subzone, and therefore straddling the base of magnetozone M18r. Promising micropaleontological markers are the FADs of *Nannoconus steinmannii minor* and *Nannoconus kamptneri minor*, plus the base of the Calpionella alpina Zone, and the bloom(s) of *Calpionella alpina* and *Crassicollaria parvula*. The testing and calibration of this constraining event-matrix in the most complete and fossiliferous sections is our task for the near future.

Riassunto. Numerosi indicatori biologici hanno il potenziale per contribuire a definire ogni ipotetico limite nell'intervallo tradizionale della base del Berriasiano. Questo intervallo è compreso tra la base della Sottozona a Berriasella jacobi e la base della Sottozona a Pseudosubplanites grandis, attraverso la base della magnetozona M18r. Indicatori micropaleontologici promettenti sono i FADs di *Nannoconus steinmannii minor* e *Nannoconus kamptneri minor*, oltre alla base della Zona a Calpionella alpina, e le fioriture di *Calpionella alpina* e *Crassicollaria parvula*. La verifica e la calibrazione di questi eventi nelle sezioni fossilifere più complete rappresenta il nostro compito nell'immediato futuro.

Introduction

This paper reviews the activity of the Berriasian Working Group (WG) of the International Subcommis-

sion on Cretaceous Stratigraphy (ISCS) in the last two years, and, more particularly, of progress made with consideration of a workable base for the Berriasian since its meeting in Milan (Italy) in March 2009. This paper is written by a few, but on behalf of all those in the WG who are contributing to the study. We use this as an opportunity for the working group at large to share its thinking with a wider community, and to invite participation. Our work is founded on the integration of useful J/K stratigraphic markers provided by a number of fossil groups – e.g. calpionellids, calcareous nanofossils, ammonites and palynomorphs – as well as magnetostratigraphy and cyclostratigraphy.

It is not an accident that the base of the Cretaceous is the last system boundary to have a GSSP: it is fraught with problems and complications. In trying to define a correlatable datum to fix the base of the Berriasian, we currently concentrate on Tethys and its margins, because Tethys constitutes most of the J/K boundary world, and the area most studied. Any boundary criteria must be tested and settled there first. We are only two years into acting collaboratively as a working group, and this paper outlines some of the problems, some of the issues and some substantive possibilities. It does not deal with all the small provincial corners

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of the globe, yet, nor all fossil groups or other indicators, nor can we yet give rounded answers to all the questions that this most difficult of intervals poses. We do not believe that magnetostratigraphy alone can provide a boundary. We cannot say that magnetostratigraphy and nannofossils are enough to define a boundary: most key Boreal sections have yielded no results for these. Nannofossils are extremely accurate stratigraphic indicators, but have not yet been proved in a wide enough area, and often not where there are plentiful ammonites. Calpionellids in Tethys are widespread, often occurring with ammonites, and have been well studied: they provide a firmer basis for the definition of a boundary. And, of course, we cannot exclude consideration of ammonites.

Historical

The stratigraphic community has been 'frozen' for years, with no agreement on a practical, widely applicable marker that could act as a base for the Cretaceous. Some simple reasons for this are that the world at the end of the Jurassic and the beginning of the Cretaceous was marked by faunal and floral endemism, and it has been divided by some authors into three realms (Tethyan, Boreal and Austral) linked on rare occasions by narrow seaways, and characterized by the widespread occurrence both below and above any possible boundary of non-marine facies, the last stretching from the yet-to-open North Atlantic (Irish Sea) across western Europe (UK, France, Iberia, Germany, the Baltic and Poland), and then again eastwards to Mongolia and China, as well as in the USA. No single biostratigraphic marker can link such non-marine rocks with the sedimentary sequences of marine Tethys and the different facies of the other marine areas, such as, for instance, the condensed siliciclastics of the North Sea basin or the Russian platform. Even within each of the marine realms and the non-marine areas, no one biostratigraphic framework operates, and no single biozonation. As one example, the so-called Boreal Realm is itself very far from homogeneous, having for its regions (western Canada, Svalbard and Barents Sea, East Greenland, North Atlantic, Russian Platform and Siberia), at least, six quite separate ammonite or bivalve biozonations, reflecting endemic faunas and difficulty or impossibility of consistent correlation. This has been the puzzle that has stopped any progress for generations, and even the finding of a common 'language' to discuss the issue. No wonder that it has not proved possible to find a globally applicable boundary. This is a preliminary note on correlative possibilities and we do not yet consider details of palaeogeography, but several references of relevance have appeared, to cite only a few: Dercourt et al. 1993,

2000; Sey I. & Kalacheva E.D. 2000; Stampfli et al. 2001; Baraboshkin 2002; Houša et al. 2007; Alsen & Mutterlose 2009; Stampfli & Hochard 2009; Meijers et al. 2010.

The story of a basal boundary for the Cretaceous started with Jurassic workers and in a boreal area, with Brongniart's (1829) erection of Portlandian and Purbeckian stages for already described rocks in England and northern France. We now know that the Berriasian part of the Purbeck Formation (with its palaeosoils, evaporites, reptiles, insects and mammals, and marine intercalations) is about 100 m in thickness. But for more than 100 years Purbeck sequences across northern Europe could only be zoned using ostracods, which in some cases proved to be strongly facies controlled. Even so, some 'freshwater' species were identified in regions as far apart as England and Poland (*Cypridea posticalis*), and even Mongolia (*Cypridea setina*). D'Orbigny (and Opel) used the last ammonite, his last marine index (*Ammonites giganteus* Sowerby, found immediately below the Purbeck Formation) to mark the end of the Jurassic: thereby the Purbeckian was eliminated to the Cretaceous. Next, Purbeck facies intercalations were to be recognized in lower Cretaceous marine sequences in the Jura, sandwiched between ammonite-bearing beds which would in time be assigned to the middle Berriasian. As far as later correlation and stage nomenclature were concerned, the non-marine areas seemed totally barred from consideration. The Purbeck was thought a 'brick wall' to correlation, having no ammonites, the group regarded as the key to correlation at the J/K boundary, as it had been for the Jurassic below (Wimbledon 2007). It seemed that only the marine areas could provide the key. The puzzle narrowed to trying to equate the marine carbonates of western Mediterranean Tethys (in a range of settings – shelf, slope, pelagic-rise/ 'platform' and trough) with Crimea, and then the North Sea margins and Russian platform (Pavlov 1889; Casey 1973). There were later extensions of study to Greenland (Spath 1947, 1952; Donovan 1957) and Siberia (Ershova 1969; Shulgina 1969) and, in Tethys, to North Africa and via Bulgaria to the Caucasus. Most work, as today, was concentrated in Tethys. But the wider and most pressing issue has remained, in particular, how to equate contrasting facies and environments: Purbeck sabkha and freshwater-lake deposits, Tethyan limestones, for instance condensed *rosso ammonitico*, and sediment-starved Boreal sandstones, pebble beds and phosphates. And, palaeontologically, how to match Tethys with its berriasellid ammonites (and later-found calpionellids and radiolarians), as opposed to Boreal craspeditid ammonites, buchiid bivalves, belemnites etc.

After a long period, during which the lower Neocomian referred, vaguely, to marine equivalents of the largely non-marine Purbeckian, Mazenot (1939) restricted the basal stage of the Cretaceous to a three-part

Berriasian, with the zone of *Berriasella grandis* at its base. This was reinforced by two colloquia [at Lyon (1963) and Lyon/Neuchatel (1973)] which took formal votes that adopted, respectively, the ammonite assemblages of the *Pseudosubplanites grandis* and *Berriasella jacobii* subzones as indicators for the base of the Berriasian. During the Second International Symposium on Cretaceous Stage Boundaries [Brussels, Belgium (1995)], the base of the Berriasian as well as the J/K boundary were further discussed, with no recommendation of change. An *ad hoc* working group agreed upon the need to investigate the Tethyan realm first for the definition of the J/K boundary, and to maintain the base of the Cretaceous at the base of the Berriasian (Zakharov et al. 1996). The overwhelming majority of authors have continued to use the *Berriasella jacobii* subzone (base of *P. grandis* zone) or *Pseudosubplanites grandis* subzone in defining a stage base, or a vaguer *grandis* or *jacobii/grandis* zone. Some now think that these subzones are not really separable, though there has been no modern reassessment of the relevant lower Berriasian ammonites. That notwithstanding, in Tethys, essentially from Mexico to the Russian Far East, and even outside Tethys, work on fixing a boundary has continued to concentrate on trying to correlate with a Berriasian base at this level. And thus it was that this interval was chosen for detailed examination by the new Berriasian WG at its inaugural meeting in Bristol (UK) in 2007, and field studies started in earnest in 2009.

More recent advances

Subsequently, widespread identification of calpionellids in Tethyan regions, often related to ammonites, began to afford a parallel framework (Le Hégarat & Remane 1968; Allemann et al. 1975; Enay & Geysant 1975; Busnardo et al. 1979). And by force of consistent application, the *Calpionella alpina* Subzone became a preferred alternative, or an unavoidable surrogate, in identifying the level of the base of the Grandis Zone. In those Tethyan sequences where no ammonites were to be found, calpionellids became and remain the dominant biostratigraphic tool (Pop 1976; Trejo 1976, 1980; Bakalova 1977; Makarieva 1979; Jansa et al. 1980; Borza 1984; Borza & Michalík 1986; Nagy 1986; Remane et al. 1986; Tavera et al. 1986, 1994; Altiner & Özkan 1991; Bucur 1992; Laková 1994; Pop 1994; Oloriz et al. 1995; Reháková 1995; Skourtsis-Coroneou et al. 1995; Adatte et al. 1994, 1996; Pyszczółkowski 1996; Grün & Blau 1997; Reháková & Michalík 1997; Houša et al. 1999; Pyszczółkowski et al. 2005; Boughdiri et al. 2006; Andreini et al. 2007; Reháková et al. 2009; Pruner et al. 2010).

It was just before the earliest of these developments that the stage name “Purbeckian” was finally suppressed by stratigraphic committees. Ironically, the event came just as new studies on palynomorphs – spores, pollen and marine dinocysts – finally made correlations possible within the Purbeck basins, and from there to both the marine Boreal and to the type Berriasian [see, for instance, Dörhöfer & Norris (1977), and references in Abbink et al. (2001) and Hunt (2004)]. Thus, at last and for the first time, some independence of facies was achieved. Oil exploration continued to drive palynological research and took it into the ‘Tethyan’ North Atlantic, to the Canadian and US eastern seaboard and into the northern North Atlantic and circum-Arctic regions.

Soon after, the discipline of magnetostratigraphy made its appearance, and a string of papers by Larson, Lowrie, Steiner, Ogg and Channell revolutionized correlation by affording a method independent of realm and fossil endemism, and to some extent facies. In Tethys, most notably in Italy, and then also in the non-marine and into offshore Tethys and the opening southern North Atlantic (e.g. DSDP 534, Ogg 1983), new results afforded independent constraints on biostratigraphy (Lowrie & Channell 1984; Ogg & Lowrie 1986). In the Tethyan setting, the calibration of palaeomagnetic results with calcareous microfossils was another notable step forward (e.g. Ogg et al. 1984; Channell & Grandesso 1987; Channell et al. 1987; Bralower et al. 1989; Ogg et al. 1991), and lately it has been revised and improved (Houša et al. 1999, 2004, 2007; Grabowski & Pyszczółkowski 2006; Channell et al. 2010; Grabowski et al. 2010). There has in recent times, at last, been an acceptance that ammonites alone are unlikely to ever effect consistent and widely applicable correlation, nor can they contribute in the widespread non-marine sequences. In contrast, magnetostratigraphy has been seen by some as a substitute for the less than universal biostratigraphic indicators. It, at least, provides a precise global indicator that can help constrain and calibrate biostratigraphy. Magnetostratigraphers, pragmatically, have seen magnetozones M18r as a workable J/K boundary indicator, being the first long, reversed interval (after the very long M19n) as one works up-sequence from the Jurassic.

Several features typify the base of the Berriasian as it has normally been defined – the base of *Pseudosubplanites grandis* Zone (?= base of *Alpina* Subzone of the standard *Calpionella* Zone): features which are both conducive to correlation and possible finer definition of a boundary. A fairly abundant, more diverse, ammonite fauna typifies an undivided Grandis Zone, as compared to much less diverse assemblages seen in the ammonite subzones immediately below and above (e.g. Hoedemaeker 1982, fig. 2). This *jacobii/grandis* assem-

blage is widespread in western Tethys. The Jacobi Subzone marks the “second ammonite renovation” of Tavera et al. (1986), Himalayitidae giving way to Berriasellidae.

The controlling factors for these changes of diversity are not clear, but oceanographic change seems to have had an even more visible role where microfossils are concerned. In fact, calcareous nannoplankton underwent rapid diversification at about the Jurassic/Cretaceous boundary, including the appearance of several highly successful and long-ranging Cretaceous taxa. In particular, several nannolith species appeared and evolved rapidly in the Tithonian, with nannoconid dominance beginning at the start of the Berriasian (Tremolada et al. 2006). Three nannoconid species (Figs 1, 2) and subspecies, in particular, make their first appearance just below and above the boundary level. *Nannoconus* flourished in warmer and possibly more nutrient-depleted surface waters than other genera (Erba 1994, 2004, 2006). The rain of heavily calcified nannoconids to the seafloor was larger than that of average coccolithophorids, and the J/K evolutionary event was responsible for a change in both carbonate cycling and burial in the oceans (Roth 1989; Weissert & Erba 2004). Such findings suggest palaeoceanographic changes across the boundary (Price 1999; Abbink et al. 2001). The intervals of higher abundances of nannoconids coincide with the abundance distribution of small calpionellid species (late Tithonian *Brevis* Subzone and early Berriasian *Alpina* Subzone). Thus, Michalík et al. (2009) concluded that both these groups of microorganism inhabited similar environmental niches.

In contrast to ammonite endemism, *Calpionella alpina* has been recorded from Mexico to Tibet, and probable calpionellids have been noted in New Guinea and, doubtfully, in western Australia. Blooms of small globular *Calpionella alpina* at the beginning of the Alpina Subzone of the Calpionella Zone (about the level of the base of the Grandis Zone) are a distinctive and widespread feature (Remane et al. 1986; Borza & Michalík 1986; Nagy 1986; Altiner & Özkan 1991; Bucur 1992; Laková 1994; Pop 1994; Oloriz et al. 1995; Reháková 1995; Skourtsis-Coroneou et al. 1995; Adatte et al., 1994, 1996; Reháková & Michalík 1997; Grün & Blau 1997; Houša et al. 1999, 2004; Pszczółkowski et al. 2005; Boughdiri et al. 2006; Andreini et al. 2007; Michalík et al. 2009; Reháková et al. 2009). The phenomenon appears fairly consistent, starting at or just below the base of the Alpina Subzone (to some extent a matter of the concept and definition of the biozone), and it offers prospects for refined correlation. The WG is most involved with taxa and their ranges, the primary evidence that will facilitate correlation, rather than on the artifacts which are biozones, but necessarily some attention will be given to the latter. Another calpionellid bloom,

of *Crassicollaria parvula*, has been identified at Brodno, Bosso and Puerto Escaño (Houša et al. 1999, 2004; Pruner et al. 2010).

Directions for WG study

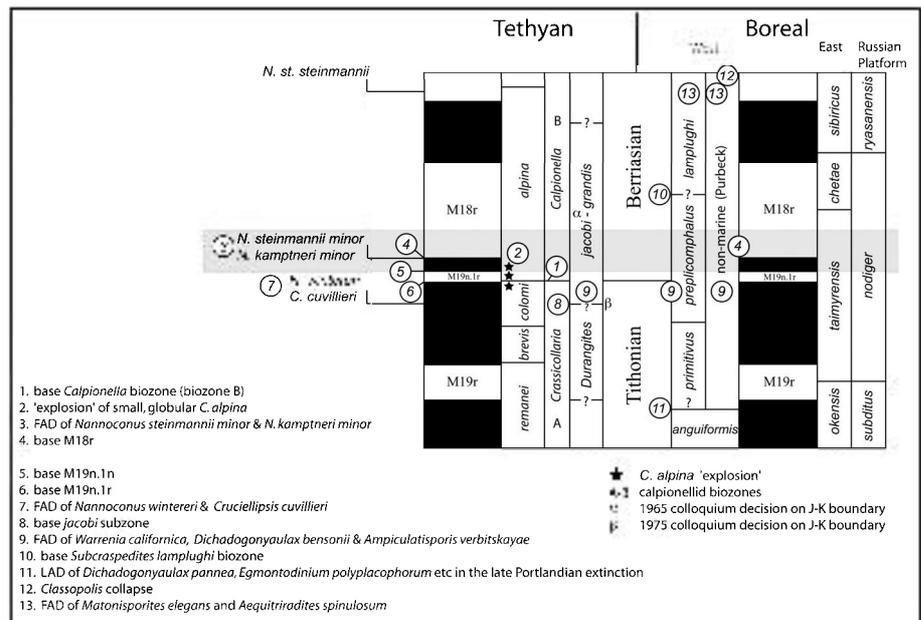
Ammonite problems in Tethys in the J/K interval

The original conception of the Berriasian was entirely ammonite based, and ammonite biostratigraphy still has much to contribute to the definition of a J/K boundary. The database of ammonite occurrences is substantial, mostly Himalayitidae and Berriasellidae, for instance: SE France (Djanélidzé 1922; Mazenot 1939; Le Hégarat 1971; Cecca et al. 1989a, 1989b), Crimea (Retowski 1893), Bulgaria (Nikolov 1960, 1982; Sapunov 1977, 1979), Algeria (Roman 1936; Benest et al. 1977; Tchoumatchenco et al. 1995) and Tunisia (Arnould-Saget 1953; Memmi 1967; Memmi & Salaj 1975; Donze et al. 1975; Busnardo et al. 1976, 1985; Boughdiri et al. 1999), Spain (Enay & Geyssant 1975; Hoedemaeker 1981, 1982; Tavera 1985; Tavera et al. 1986, 1994; Oloriz & Tavera 1989) and Morocco (Benzaggagh & Atrops 1997; Benzaggagh 2000). Additionally, some recent palaeontological contributions by Cecca et al. (1989a, 1989b) and Enay et al. (1998a, 1998b, 1998c) describe new genera and species from the late Tithonian and early Berriasian of SE France, Algeria, Tunisia and Spain.

The Berriasian WG is re-visiting these faunas, re-examining the validity of taxa and primary data on their ranges, and the definition of previously proposed biostratigraphic units. This currently involves sites from Crimea to Mexico. In addition to endemism, salient issues that still exist and await consideration are:

- comparisons of fossils with different preservational states makes taxonomy very difficult, e.g. comparing pyritic nuclei from Tunisia and the crushed moulds of Bulgaria and Rio Argos (Spain) – which clearly affects attempts to identify taxa and produce range charts;
- the Bochianitidae and Spiticeratinae are in urgent need of revision, and little notice has been taken of so called ‘long-ranging’ taxa of the Haploceratinae, Phylloceratinae and Lytoceratinae;
- ammonite distributions plotted bed by bed against accurate lithological logs are not available (Algeria, Bulgaria), or columns lack sufficiently illustrated fossils (Tunisia);
- discontinuous distribution of species through a sequence (common in the Vocontian domain of SE France), scarcity of fossils (Tunisia), or poor exposure of key intervals (Occitanica Zone, Rio Argos), or sizable barren intervals (18 metres between last appearance

Fig. 1 - Markers under examination as potentially useful in defining the Jurassic/Cretaceous boundary interval.



of *Pseudosubplanites euxinus* and first occurrence of *Tirnovella subalpina*, Rio Argos);

- long-range correlations in some cases need careful reconsideration, due to possible misidentifications of species (e.g. of *Retowskiceras* species in Spain and Crimea).

There are a number of obvious solutions and lines of study:

- examination of critical taxa to settle taxonomic disputes and uncertainties;
- more integration of ammonite data with sedimentological/lithostratigraphic and biostratigraphic analyses, as well as purposeful collecting of microfossils in tandem with ammonites;
- detailed collecting of the key intervals, e.g. base *Jacobi* Subzone, base *Grandis* Subzone, and integration of better defined biostratigraphic units, including, initially, sections in SE France (e.g. Berrias, Les Combes, Chouet etc), as well as Crimea, southern Spain etc.

Progress

In the first three meetings of the new Berriasian WG, consideration has focussed on a boundary interval in the lower and middle *jacobi/grandis* Zone, and specifically on the best markers already identified in Tethys and, importantly, some of the better correlative tools for achieving correlation with both Boreal marine and non-marine (Purbeck) sequences: wider correlation being the primary aim. One of levels for concentrated study had to be the base of Calpionellid biozone B, because it has in recent years become a *de facto* working base for the Berriasian Stage amongst a wider group of workers.

One issue still to be addressed is the different uses and definitions of the *Calpionella alpina* Subzone (e.g. Houša et al. 1999; Boughdiri et al. 2006; Andreini et al. 2007; Michalík et al. 2009).

Our determination as a group has been to make progress with multidisciplinary correlations, markers from one group reinforcing others. The aim is to identify as many markers as possible in any given area, forming a self-reinforcing matrix: and then assessing what works between regions.

In summary, as a first step, the WG has agreed that, initially, the interval offering the best opportunities for study, because it is the one with most, well-defined, markers, is at about the base of M18r (Fig. 1). The upward sequence from the middle of M19n through M19n.1r, M19.1n and into M18r, in particular, provides several well-established datums in close order, notably based on calpionellids and calcareous nannofossil ranges, the calpionellid biozonation, nannofossil FADs and magnetostratigraphy. In particular, four reliable well-marked datums occur in an even shorter interval giving a core framework for comparison. These are 1) the base of *Calpionella* Zone (B Zone) and the sudden decline of species of *Crassicolonia*, 2) the 'explosive' appearance of a monospecific association of small, globular *Calpionella alpina* (referred to by authors as the *alpina* "acme", or the *alpina* "bloom") (Remane 1985; Remane et al. 1986; Altiner & Özkan 1991; Bucur 1992; Laková 1994; Pop 1994; Tavera et al. 1994; Oloriz et al. 1995; Skourtsis-Coroneou et al. 1995; Grün & Blau 1997; Reháková & Michalík 1997; Houša et al. 1999; Pszczółkowski et al. 2005; Boughdiri et al. 2006; Andreini et al. 2007; Reháková et al. 2009; Pruner et al. 2010), 3) the FAD for two subspecies of *Nannoconus* (*N. steinmannii* minor and *N. kamptneri* minor) and 4) the base

of M18r. In all cases, these are horizons which have been widely and consistently recognized. Macrofossil datums will be linked to this framework, and, for instance, foraminiferal, radiolarian, geochemical and cyclostratigraphic signals must also be added in due course.

Thus primary markers and secondary constraining datums (Fig. 1) can be listed as follows:

Primary markers

1. base of the *Calpionella* Zone – *alpina* Subzone
2. ‘explosion’ of small, globular *Calpionella alpina*
3. FAD *Nannoconus steinmannii minor* and *Nannoconus kamptneri minor*
4. base M18r

Secondary supporting markers

5. base of M19n.1n
6. base of M19n.1r
7. FADs of *Nannoconus wintereri* and *Crucellipsis cwvillieri*
8. base of *Berriasella jacobi* Subzone
9. FADs of *Warrenia californica*, *Dichadogonyaulax bensonii* and *Apiculatisporis verbitskayae*
10. base of *Subcraspedites lamplughi* Zone
11. base of *Pseudosubplanites grandis* Zone
12. LADs of *Dichadogonyaulax pannea*, *Egmontodinium polyplacophorum* etc. in the late Portland extinction.
13. FADs of *Matonisporites elegans* and *Aequitriradites spinulosum*.

The sampling of nannoconids in northern Italy, with frequent and precise sample points, offers good prospects for recognition of useful datums. In the section at Torre de’ Busi, where sampling has been at a much closer interval than is normally the case, nannoplankton FADs are very precisely located (linked to magnetostratigraphic coring): *N. steinmannii minor* in the topmost portion of M19n.1n and *N. kamptneri minor* in the basal part of M18r (Casellato et al. 2010). These two datums (and other nannoconid markers above and below) are viewed as being more accurately and ‘correctly’ placed here than in less intensively sampled sequences (Fig. 2). This requires that earlier-studied sequences, where sampling points were fewer and further apart, need to be re-examined, so as to achieve comparable precision (e.g. Fiume Bosso and Foza). Another section that has received comparably close study and sampling is Brodno (Michalik et al. 2009). And there, although *Nannoconus wintereri* and *Crucellipsis cwvillieri* have the same position as at Torre de’ Busi, in mid M19n, *N. steinmannii minor* and *N. kamptneri minor* have their FADs about 1.3 m above the base, of M18r. This may be because of the obscuring effects, ‘noise’, of abundant other microfossils.

Though progress is being made in Tethys in integrating micro- and macrofossil markers and magnetostratigraphy, a major challenge is trying to link to the Boreal and its parts. As said, the intermittent marine connections within the Boreal Realm have long hampered a single zonal scheme using ammonites. As to correlations directly between Tethys and the Boreal, apart from a few salient ammonite links (well below and well above any putative Tithonian/Berriasian boundary), there are some important tie points afforded by palynology. Although, in the interval being studied, it is not possible to correlate with all the several landlocked embayments of the Boreal, correlation can at least be achieved between the western Mediterranean and the Norway-Britain-Netherlands boreal marine embayment. Similarly, palynomorphs link Tethys to the Anglo-French basin and the predominantly non-marine Purbeck facies. This is in the M19n-M17r interval. The FAD of the palynomorphs *Warrenia californica*, *Dichadogonyaulax bensonii* and *Apiculatisporis verbitskayae* occurs at Berrias (in bed 146), in the Subcraspedites preplicomphalus Zone in the North Sea Basin, and also in the Purbeck sequence at Durlston Bay, in the Hard Cockle Beds (mid M19n). Another FAD occurs just below the top of M19n at Durlston: that of *Dapsilodinium warrenii* and *Cantulodinium arthuriae*, but this has yet to be identified more widely. At a higher level, the FAD of *Matonisporites elegans* and *Aequitriradites spinulosum* has been identified in the Durlston Cherty Freshwater beds (M17r) and in the Subcraspedites lamplughi Zone in the North Sea basin (Abbink et al. 2001). As the Subcraspedites preplicomphalus Zone (with *Craspedites plicomphalus* Sowerby) and the S. lamplughi Zone have been broadly equated with the C. nodiger Zone and higher on the Russian platform (= ?Craspedites taimyrensis and Chetaetes chetae zones of Siberia) (Casey 1973 etc; Harding et al. in press), the palynomorph levels indicated, and their associated magnetostratigraphic zones, may be related to the record of M18r at Nordvik (Houša et al. 2007).

A way ahead

Having discussed the consistency of proposed datums overall, the WG now studies and examines further the precise stratigraphic relationships in this limited interval; that is, testing current assumptions on the sequence of the four datums, on their ranges, relationships to one another and to other datums, notably the base of the Jacobi and Grandis ammonite subzones (Tab. 1). This work (on calpionellids, ammonites and nannofossils, with magnetostratigraphy) is presently in progress at sites in southern France and Crimea, and is extending to Tunisia and Bulgaria in early 2011. Group

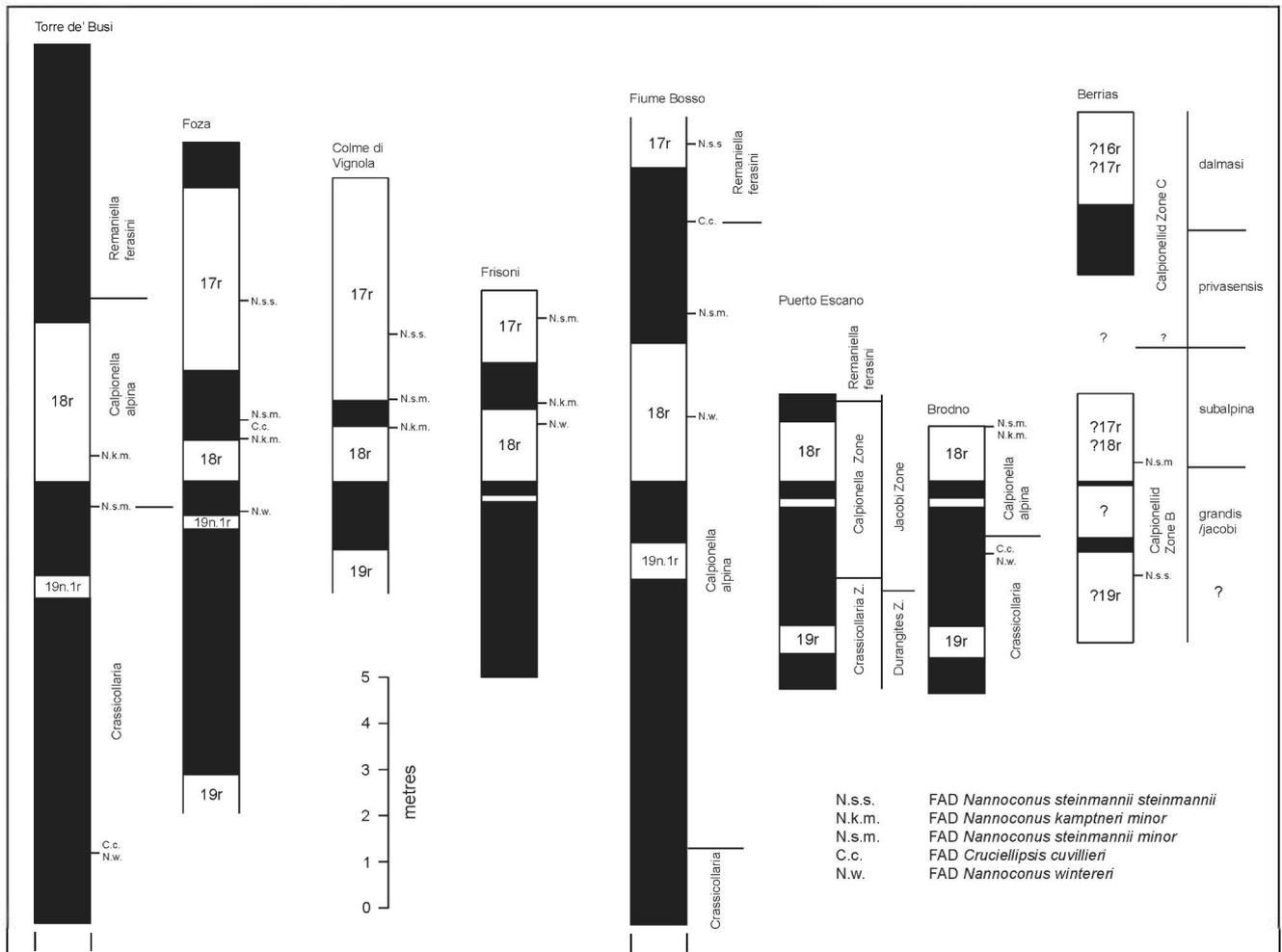


Fig. 2 - Comparison of critical Tethyan sections at the level of M18r. Torre de' Busi, Foza, Colme di Vignola and Frisoni after Channell et al. 2010, Casellato, 2010; Fiume Bosso after Bralower et al. 1989, Houša et al. 2004; Puerto Escaño after Tavera et al. 1994, Pruner et al. 2010; Brodno after Michalik et al. 2009; Berrias after Galbrun, Rasplus & Le Hégarat 1986, and Jan Du Chene et al. 1993.

members are active in Argentina and Tibet, and work is starting to review older results in Mexico. In addition, thought is being directed to secondary markers which could be tied directly to the primary datums, or interdigitated between them, allowing correlation to wider geographical areas. Thus the work of the WG in coming months is of precise calibration of biostratigraphic markers in the chosen M18r interval. The base of M18r has been chosen as a significant event, in preference to the short magnetic intervals below (M19n1r, M19n.1n) – because such short magnetic intervals are very much less easy to detect in shallow marine and non-marine settings (and may require a high sampling rate). The list above is far from exhaustive and more data will be added, to reinforce the framework that is emerging.

Clearly our approach is constrained by the fact that the fullest range of evidence of the kind discussed here comes from sequences in the Tethyan Realm: whereas in Boreal regions things are less well understood and the number of useful biostratigraphic indicators (other than endemic ammonites or *Buchia*) are far

fewer in number. And diversity of, for instance, microfossils/palynomorphs is considerably lower. Though some (Portland/Purbeck) localities in England and northern France have a magnetostratigraphic record, that can only be said of one other boreal site, Nordvik in northern Siberia (though there is unpublished data on the thin Tithonian-Berriasian boundary sequences on the River Volga (Guzhikov, pers. comm.).

The WG's primary task is to find effective correlative tools that make possible correlations to the non-marine, to the Austral and Boreal regions. Though many more coherent sequences of the 'right' age have been identified and documented in Tethys, and most workers are active there, we must look beyond Tethys. The full application of palynology, cyclostratigraphy, geochemistry, radiolaria, foraminifera has yet to be assessed: they too offer more possibilities for finer calibration. The refinement of inter-realm and non-marine/marine correlations using palynomorphs is one focus that the WG already pursues (Harding et al., in press). Similarly, more intensive study of the distinct Boreal

GEOGRAPHIC AREA	Event VS Section	AUTHORS	AGE	FAD <i>N. steinmannii minor</i>	FAD <i>N. kamptneri minor</i>	FAD <i>N. wintereri</i>	FAD <i>C. cuvillieri</i>	FAD <i>N. colomi</i>
Southern Alps (Italy)	Torre de' Busi	Casellato 2010; Channell et al. 2010	Oxfordian-Berriasian	M19.9n; ACME Calpionella alpina spherical form	M18.3r; lower Calpionella Zone	M19.5n; mid C.intermedia Subzone	M19.4n; mid C.intermedia Subzone	M18.6r; mid Calpionella Zone
	Monte Pernice	Erba & Quadrio 1987	Tithonian/Berriasian	–	–	–	–	~ base Calpionella Zone
		Casellato 2010		~ lowermost Calpionella Zone	~ lower Calpionella Zone	~ lower Crassicolliaria Zone	~ mid Crassicolliaria Zone	–
	Colme di Vignola	Casellato 2010; Channell et al. 2010	Oxfordian-Berriasian	M17.1r	M18.9r	M18.5r	–	–
	Frisoni	Casellato 2010; Channell et al. 2010	Kimmeridgian-Berriasian	M17.1r	M18.9r	base M18n	–	–
	Foza	Bralower et al. 1989	Callovian-Berriasian	M18.8r	–	M18.8r	–	–
		Casellato 2010; Channell et al. 2010		M18.2n	–	M19.9n	–	–
	Kaberlaba	Martire et al. 2006	Oxfordian-Berriasian	base Calpionella Zone	–	–	–	–
Rabeschini	Martire et al. 2006	Oxfordian-Berriasian	base Calpionella Zone	–	–	–	–	
Xausa	Channell et al. 1987	J/K boundary	M19.7n; Upper Crassicolliaria Zone	–	–	–	–	
Appennine (Italy)	Fiume Bosso	Bralower et al. 1989	(Middle Bajocian) - Late Kimmeridgian - Berriasian	M18.8r	M17.3r	M18.5r	M18.8r	–
	Fonte Giordano	Bralower et al. 1989	Late Kimmeridgian - Berriasian	M18r?	–	–	–	–
Austrian Alps	Nutzhof	Rehakova et al. 2009	J/K boundary	base elliptica Subzone	mid lowermost Calpionella Zone	mid lowermost upper Crassicolliaria Zone	–	–
		Pruner et al. 2009		M17r	(upper?) M18n	lower M19r	–	–
Spain	Puerto Escano	Tavera et al. 1994	J/K boundary	~ FO Calpionella elliptica; Jacobi Ammonite Zone	–	upper Durangites Ammonite Zone	~ FO Calpionella elliptica; Jacobi Ammonite Zone	–
		Pruner et al., 2010	J/K boundary	–	–	–	–	–
	Carcabuey	Bralower et al. 1989	Tithonian	–	–	–	–	–
South France	Broyon	Bralower et al. 1989	J/K boundary	A/B boundary	mid A1 Zone	mid A1 Zone	A/B boundary	–
Western Carpathian (Slovakia)	Brodno	Michalik et al. 2009	J/K boundary	M18r; Calpionella Zone	M18r; Calpionella Zone	M19.6n; lower Colomi calpionellid Subzone	M19.6n; lower Colomi calpionellid Subzone	–
Southern Carpathians (Romania)	Svinita	Melinte 1991	Tithonian - Hauterivian	Lower Calpionella Zone (* <i>N. steinmannii minor</i> and <i>N. steinmannii steinmannii</i> were not distinguished)	–	–	–	–
Volga Basin, Russia	Gorodische & Kashpir sections (Volgian stratotype)	Kessel et al. 2003	Volgian stratotype	no <i>Nannoconus</i> reported			–	–

DATA IN PROGRESS

GEOGRAPHIC AREA	Event VS Section	AUTHORS	AGE	FAD <i>N. steinmannii minor</i>	FAD <i>N. kamptneri minor</i>	FAD <i>N. wintereri</i>	FAD <i>C. cuvillieri</i>	FAD <i>N. colomi</i>
Spain	Rio Argos	Hoedemaker & Leereveld 1995	J/K boundary (section Z)	–	–	–	–	lower Berriasiella Zone; Calpionella Zone;
		Gardin & Casellato	J/K boundary (section Z)	lower Berriasiella Zone; Calpionella Zone	lower Berriasiella Zone; Calpionella Zone	~ base Berriasiella jacobi Subzone; Calpionella Zone	~ base Berriasiella jacobi Subzone; Calpionella Zone	uppermost Berriasiella jacobi Subzone; lower R.cadischiana Subzone

DSDP and ODP sites

GEOGRAPHIC AREA	Event VS Section	AUTHORS	AGE	FAD <i>N. steinmannii minor</i>	FAD <i>N. kamptneri minor</i>	FAD <i>N. wintereri</i>	FAD <i>C. cuvillieri</i>	FAD <i>N. colomi</i>
Central Atlantic	DSDP 534	Bralower et al. 1989	Late Kimmeridgian-Berriasian	M18.5r	M18.5r	M19.7n	M19.5n	–
		Casellato, 2010	–	M18.4r	M18.4r	M19.8n	–	–
	DSDP 105	Wilcoxon 1972	Late Jurassic	reported <i>Nannoconus</i> ssp.			–	–
Argo Abyssal Plain, NW Australia	ODP site 261	Bown 1992; Bown & Cooper 1998	Late Jurassic	no <i>Nannoconus</i>			FO at 31-3, 40 (upper M19n?)	–
Central Pacific Ocean; Magella Rise	DSDP 167	Roth 1973	Late Jurassic	–	–	–	93 CC	94-2, 56-58
South Spain	ODP 901	De Kaenel & Bergen 1996	Tithonian	–	–	–	FO at 3-1, 2	–
Falkland	DSDP Site 330	Wise & Wind 1977	Late Jurassic	–	–	–	–	–
	DSDP Site 511	Wise 1983	Late Jurassic	–	–	–	–	–

Tab. 1 - Comparison of FADs of calcareous nannofossil species from onshore and offshore localities.

ammonite faunas is in progress, so as to allow the calibration of the limited magnetostratigraphic results that are already available in that realm. Much detailed study and refinement of existing data lies ahead. We also need to investigate the deep-sea sections recovered at DSDP and ODP sites (Tab. 1), to verify the nannofossil and calpionellid datums, calibrated, where available, with magnetostratigraphy. This will ensure exportability of the Tethyan framework to other oceanic basins.

There is much to do, and the early months of study and re-assessment make one feel that perhaps, where some classical sites are concerned, we do not know as much as we thought at the outset.

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