The Jurassic-Cretaceous boundary interval has been problematic since the start of stratigraphic study. This is reflected in different stage names being employed in Boreal and Tethyan realms below and above the putative boundary. Despite attempts at homogenisation where stage terminology is concerned, correlative precision over long distances at or close to a boundary has not yet been achieved. But the new Berriasian/ J-K boundary working-group of the Cretaceous Subcommission is now attempting to remedy this situation.

Introduction

The Berriasian is not a “marine stage”, as one sees written sometimes: it is the one and only name for the initial stage of the Cretaceous System, and the first “age” of the period. It needs to be, but is not yet, definable in a GSSP. That datum must be readily correlatable, traceable as much as possible around the world—utility being the major consideration. But this J-K boundary interval is correlative one of the most difficult, and it is not chance that it is one of the very last GSSP tasks to be tackled by the ICS and its subcommissions. Removal by mid-Cretaceous erosion over large regions, faunal separation into boreal and tethyan ‘realms’, prolonged isolation of individual basins within these, and the prevalence of non-marine sequences across the boundary have combined to afford a correlative enigma for geologists since the start of stratigraphical study. Cracking this ‘nut’ in a coherent and lasting fashion is one of the larger challenges for the ICS.

The story of attempts to place the Jurassic-Cretaceous boundary was for several generations one of placing an upper limit to Jurassic marine sequences across the boundary have combined to afford a correlative enigma for geologists since the start of stratigraphical study. Cracking this ‘nut’ in a coherent and lasting fashion is one of the larger challenges for the ICS. Tithonian by Kilian, and Toucas even placed the stage in the Jurassic (Arkell, 1956). For Kilian (1907–10), the base of the Berriasian was actually the Fauriella boissieri zone, and for Mazenot (1939) the horizons of Kilian became the three subzones of Berriasella grandis, B. boissieri s.s. and Kilianella aff. pexipyccha. It can be said that the Berriasian basal biozone, the jacobi/grandis interval, is still somewhat lacking definition, and the problem of taxonomic diversity and low fossil numbers that beset the uppermost Tithonian and the lower Berriasian in the area remain an impediment. But only these lower levels have ever seriously been discussed as the level to recognise a Berriasian base.

Subsequently, in 1963 and 1973, two colloquia (Lyon and Lyon/ Neuchatel) were to vote and adopt the ammonite assemblages of the Pseudosubplanites grandis and Berriasella jacobi subzones as indicators for the base of the Berriasian. These decisions, one has to say, were made by gatherings of specialists who predominantly worked in the western Mediterranean, and decisions were founded on consideration of Tethyan ammonites only. But at the time there was little else to consider. Hoedemaeker (1987) considered that the conference decisions were unlikely to be implemented in practice, and suggested the base of the Subthucommandia subalpina subzone as a more definable option. Nevertheless, the overwhelming majority of authors have continued to use the jacobi subzone (base of grandis zone) or grandis subzone in defining a stage base, or a vague gran- dis or jacobi/grandis zone. Though it has to said that on the basis of ammonite faunas themselves, these subzones are still not really divisable. That fact notwithstanding, even in the very large part of the world outside Tethys, work trying to fix a boundary has concentrated on correlating with a jacobi/grandis zone.

Todays’ world

The provincialism and facies limitations affecting faunal and floral elements—ammonites, and later-studied buchiids, calpionellids and nannofossils—has for generations prevented substantial progress with long-range correlation in the Jurassic-Cretaceous interval. Even consistent regional results have not been applicable in all areas, in all facies, or even most, let alone in all parts of a single so-called “realm”. Geologists’ inability to correlate ammonites with any great certainty even within a realm (e.g., the key Greenland-Britain-Russia triangle) has led to circularity of discussion and what have been quite unnatural schemes of zonal comparison (and stage nomenclature), that have tended to conceal the lack of actual correlation at specific level (diagrams showing what were, in truth, surmised matches) and the prevalence of inferable non-sequence.

Sometimes odd specimens of an ammonite species, or even genera, have been clutched at to derive the much hoped-for tie point and overcome the barriers imposed by endemic faunas. The contribution of Sey and Kalacheva (1997) on the correlation of the Cauca- sus, Crimea, Russian platform and western Tethys was a great step forward. Their results gave solid connections between at least some tethyan and boreal areas, for instance showing equivalence at the Dalmasceras dalmasi and Riasanites zonal levels (Figure 1); and
key magnetostratigraphic potential came with the work of Guzhikov and Eremin (1999).

We are now in a different stratigraphic world to that at the time of the earlier conferences: more of the world is better known and we have at our disposal a much better suite of stratigraphic indicators, fossil and otherwise, than were previously available. We are no longer constrained by one or two groups of fossils, and sometimes a very limited number of taxa within these. In the 1970s, no agreement was possible even on the equivalence of the Portlandian, Volgian and Tithonian, nor of where precisely a J-K boundary might sit in areas outside the western Mediterranean. On magnetostratigraphic and palynological grounds, the Portlandian-Berriasian boundary level has now been localised in western Europe, and the L-M. Volgian is now seen to span the Bolonian (=Upper Kimmeridgian) and Portlandian (Tithonian) and it is clear that the Upper Volgian has a latest Portlandian, perhaps, but mostly Berriasian age (Figure 1).

Wider and effective use of a *jacobi* subzone, following the 1973 colloquium decision, or any other alternative used in a global sense, still requires considerable thought on the matter of multidisciplinary correlation. This maximisation of correlative precision demands work on useful surrogate indicators or proxies, alternatives to the ammonites—and indeed a whole suite of alternative microfossil indicators, geochemical and palaeomagnetic techniques can now be brought to bear.

Berriasian correlation has moved on considerably in the last thirty years, with significant work carried out in several regions outside the western Mediterranean: notably in Ukraine, the Caucasus, Siberia and the Russian Far-East, as well as China and Japan. Substantial progress has been made in identifying Tethyan ammonites in Russian sequences, and also in correlating European Russia and Britain, and in those regions from Iberia to Poland with largely non-marine facies. Correlation between non-marine and marine, once not constrained by one or two groups of fossils, and sometimes a very limited number of taxa within these. In the 1970s, no agreement was possible even on the equivalence of the Portlandian, Volgian and Tithonian, nor of where precisely a J-K boundary might sit in areas outside the western Mediterranean. On magnetostratigraphic and palynological grounds, the Portlandian-Berriasian boundary level has now been localised in western Europe, and the L-M. Volgian is now seen to span the Bolonian (=Upper Kimmeridgian) and Portlandian (Tithonian) and it is clear that the Upper Volgian has a latest Portlandian, perhaps, but mostly Berriasian age (Figure 1).

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**Tethys and calpionellids**

In certain Tethyan areas lacking ammonites, calpionellids have become a key tool in biostratigraphy, such as in the pelagic limestone sequences of Italy and middle Europe. But, as to the direct equivalence of ammonite biozones and those founded on calpionellids, the situation is not entirely clear. In the 1970s, no agreement was possible even on the equivalence of the Portlandian, Volgian and Tithonian, nor of where precisely a J-K boundary might sit in areas outside the western Mediterranean. On magnetostratigraphic and palynological grounds, the Portlandian-Berriasian boundary level has now been localised in western Europe, and the L-M. Volgian is now seen to span the Bolonian (=Upper Kimmeridgian) and Portlandian (Tithonian) and it is clear that the Upper Volgian has a latest Portlandian, perhaps, but mostly Berriasian age (Figure 1).

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Galbrun's lowest recorded magnetochron at Berrias, in the grandis subzone, is perhaps assignable to M18r, which gives at least an approximation there for the position of the base of the underlying jacobí subzone in the magnetic scale. Perhaps the base of jacobí falls in M16r, which would accord with the Hard Cockle Beds of Dorset. The base of jacobí subzone in southern France has been taken to be coincident with the base of the calpionellid biozone B. However, at Bosso (Lowrie & Channell, 1982), the base of biozone B was formerly recorded within M19r.

The thick sequences of the Dorset Portland and Purbeck, the original latest Jurassic standards, have yielded a good magnetostratigraphic record (Portland formations M21n–M20n; and Purbeck Formation M20n–M13r), which when added to the Kimmeridge Clay–Portland sequence of the northern French coast (M22r–M20n) provide a useful comparative standard against which thinner Boreal and deeper-water, and more often thinner, Tethyan sections may be compared (Figure 1). Chron comparisons are clear with the pelagic or hemipelagic sequences, such as Bosso or Brodno, for instance (Figure 2).

The marine/non-marine succession in Dorset (and the Boulonnais), the original d’Orbigny type area, has been sampled for magnetostratigraphy with increasing intensity since 1987 (Figure 3). Palynocysts in bed 148 at Berrias (grandis subzone) are the same as those in the Hard Cockle beds of Durlston Bay, assigned there to magnetochron M19n (Figure 4). Other species immediately beneath the lowest ‘normal’ chron recorded at Berrias (Galbrun et al., 1986), putatively M18 and in the grandis subzone, correlate with the Cypris freestones of Dorset (lower M19n). Palynocysts in bed 149 (subalpina subzone) at Berrias (no magnetochron assigned) correlate with the same in the Scallop bed at Durlston in M16n. Hunt postulated (2004) a large hiatus between bed 146 and bed 149 at Berrias: all within calpionellid zone B, and consistent with sedimentary evidence of non-sequence, visible from the top of the Tithonique to the privasensis subzone.

The constraining biostratigraphic framework for matching the Durlston and Berrias magnetochrons had been reinforced previously by use of ammonites and ostracods. One Cypridea assemblage (fauna M4 of Detraz & Mojon, 1989), with a combination of species long only known at the top of the Dorset Intermarine beds, was located in the Jura, in beds (Fmn de Pierre Chatel) sandwiched between units

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**Figure 2** Magnetostratigraphy of selected Boreal and Tethyan sequences: Durlston pars (U.K.), Berrias (France), Cehegin and Carcabuey (Spain), Fozo, San Giorgio and Bosso (Italy), and Nordvik (Russia).
with *privasensis* and *paramimounum* ammonites. The *dalmasi–paramimounum* subzones straddle a reversed magnetochnor at Berrias, and this reversed chron there and the one which encompasses most of the Interrimarine beds at Durlston have, independently, been assigned to M16r. However, dinocysts from beds just above the ostracod-bearing level at Durlston (Scallop bed) match ostracods from the *subalpina* subzone at Berrias (oooo–Figure 4). The dinocysts (pppp–Figure 4) in the *Cypridea* (oooo) and palynomorphs (pppp), and comparable ostracod assemblages of the Jura.

As to elsewhere in Tethys (Figure 2), good magnetostratigraphic results from sequences in Spain and Italy match well with one another. The latter from sections with good calpionellid successions, but no ammonites (or palynology), and the former with ammonites and calpionellids, but poor palynology. Thicker sequences such as Bosso in Italy provide a solid magnetostratigraphy and calpionellid-based biostatigraphy, as do the more condensed pelagic successions, like Brodno in middle Europe.

**Boreal contradictions**

With J-K correlation in the so-called boreal realm, some decidedly solid problems remain. In the main this is because of the past dependence on ammonites. Post-Kimmeridge Clay times, widespread pavloviid ammonites gave way to local virgatites, dorsoplanitids and their craspeditid offshoots. This post-Pavlovia interval is still for the most part marked by mismatching faunas up to and beyond the top of the Jurassic, until assemblages with *Chaetites*, *Praetollia* and then more ubiquitous *Hectoroceras* appear, but by then we are well into the upper Berriasian (Figure 5).

The comparability of the British/French and Greenland sequences at the J/K boundary with the proximal, sediment-starved clastic deposits of Russia is still not resolved. After the *Epipallasiceras* of Greenland (faunas 40-42) and those in the early Portlandian *Progalbanites* (*Zaraiskites*) *albani* zone of England and France, some comparability of faunas to *oukensis* zone times can be seen with eastern Greenland, with later *vogulicus* zone *Crenodontes* also perhaps being comparable with English forms (Wimbledon and Bedson, 1983). But, with Russia the only possibilities for correlation are seemingly *Epivirgatites* of the *nikitini* zone. Though this seems far too early, if the approximately basal Berriasian *Kachpurites fulgens* zone is indeed conformable on the *nikitini* zone on the Volga: sediments suggest otherwise. The traditional correlation by Russian workers (Gerasimov and Michailov, 1966, etc.) was of the English *albani* zone and the Russian platform *Zaraiskites zaraikensis* subzone, of *Crenodontes gorei* with a *Virgatites virgatus* zone, and a zone of “Titanites giganteus” with *Epivirgatites nikitini*: the last based on the long-held view that *Lomonossovaella* and the so-called “*Kerberites*” in Russia could be matched with Portland Stone ammonites (Arkell, 1935; Casey, 1973). But with revision of the latest Jurassic (–earliest Cretaceous) ammonites faunas of Britain and France, greater faunal complexity and an enlarged zone scheme resulted (Wimbledon and Cope, 1978; Wimbledon, 1983). Plus the conclusion that no Portland Stone equivalents could be identified at Moscow or on the Volga, and that the “*Epiwirgatites*”, *Epipallasiceras* and pavloviids of the *albani* zone (the lowest Portlandian) were, if any, matched with the *nikitini* zone. It seemed impossible to accommodate the remaining four ammonite zones of the Portland Sand and Portland Stone formations, except between the *nikitini* and the *fulgens* zones. But this issue of internal boreal correlation, raised at the Erlangen symposium, remains: how is it possible to correlate all or even a substantial amount of the Portlandian-early Berriasian with the Volgian of Russia, if 70 m of Portland beds is being equated with solely the *nikitini* zone (the lowest Portlandian) were, if any, matched there being any representation of the four southern English Portlandian ammonite zones (*glaucolithicus to anguiformis*) and an “*oppressus* zone” in the type Volgian. The quite separate (later) sequences in eastern England with *Subcraspedites primitivus*, and then *S. prelicomphalus* are assumed (following Casey, 1973) to be equivalent to the *fulgens* to nodiger interval of the Russian plat-

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**Figure 4** Magnetostratigraphy at Durlston Bay (Dorset) and Berrias (Ardeche) with fossil datums, species of the ostracod *Cypridea* (oooo) and palynomorphs (pppp), and comparable ostracod assemblages of the Jura.
form, but they sit above a considerable hiatus and are marked internally (like biozones above) by phosphatic pebble units and erosive bases (Figure 5).

But the maintenance (Zakharov et al., 2006) of a “Paracraspedites” fauna to bridge this correlative abyss between east and west Europe and north Atlantic, matching “Paracraspedites” (one fauna of the Russian Platform) is suggested as being the same as seen at the Cherty bed/Freestone member junction on Portland (T. anguiliformis ammonite zone) is thus suggested as being the base of the lower grandis zone and the paramiospore subzone. A number of lines of evidence have led more consistently to acceptance that the paramiospore zone correlates approximately with the paramiospore subzone, around magnetostratigraphic M16r, that is, at about the Praetolites (Runctonia) runctoni zone of eastern England and the North Sea basin (Figure 1).

The thicker, and maybe fuller, sequences of the Siberian upper Volgian raise new possibilities in J-K boundary correlation. Integration of the separate ammonite zonal schemes for Siberia and the Russian platform and external correlations are given new momentum by magnetostratigraphic results from Nordvik (Houé et al., 2007). This work provides the most complete record from Russia thus far, though, compared to western European magnetostratigraphic results (Figure 2), it appears to show condensation or reduced sedimentation at about the M18 level. It is also interesting that a J-K boundary has been indicated in mid M19n in middle Europe (Houé et al., 1999), but just above the base of a putative M18n at Nordvik (Houé et al., 2007: there is a mistake with chron numbering in their figure 2). The small reversed interval recorded as M20.1r at Nordvik (in exotic ammonite zone=fulgens zone) is thus suggested as being the same as seen at the Cherty bed/Freestone member junction on Portland (T. anguiliformis ammonite zone) and in Italy at Foza, San Giorgio and Bosso (‘calpionellid zone A), perhaps M. microcanthus ammonite zone (Figure 3).

A way forward

On 5th July 2007, a new Berriasian Working Group (Subcommission on Cretaceous Stratigraphy) met for the first time in Bristol, UK. Attending members and correspondents unanimously decided to take a conservative line in its work to define the base of the stage and fix a GSSP. In trying to define a J-K boundary, it decided to maintain continuity with more recent historical understanding of the scope of the uppermost Jurassic and the lowest Cretaceous—thus to choose somewhere a GSSP, a Berriasian base, that is consistent with usage in recent decades: that is in or close to the base of the grandis (jacobi/grandis) zone. The primary task is correlation, and in coming months, in key regions, members of the WG will be collating information on correlatable markers (fossil or inorganic) within and close to that interval, markers that must have intra- and inter-regional utility.

The work only begins, but there are a number of datums which approximate, at least, to the base of the grandis zone, and provide potential proxies for its recognition and definition: for instance, the base of the Kachpurites fulgens ammonite zone, the FADs for Apiculatisporis verbiskayae in the lower Purbeck and Subcraspedites prelicomphalus of the north Sea (?=Craspedites nodiger zone of Russia) (Figure 1).

The recent identification of Subcraspedites sowerbyi also in the Epivirgatites nikitini zone on the Volga is a fascinating record. That species in eastern England has been described only from beds (the S. prelicomphalus zone: Casey, 1973) which have been consistently correlated with the Craspites nodiger zone. But its use (Zakharov et al., 2006) to suggest correlation of this nikitini zone with the prelicomphalus zone would mean that the nikitini zone would then have horizons equivalent to perhaps 5–6 ammonite biozones as defined in England.

Sey and Kalacheva’s (1997) great step forward has been the foundation for refinement in recent times, and much new work on the ammonite correlations (e.g., Mita, 2007; Zakharov et al., 2006). Mita’s finds of Dalmasceras ex gr. djanelidzei and Malbosiceras nikolovi suggested to him the correlation of the Riasanites rjasanensis zone’s lower boundary with that of the jacobii subzone in western Tethys. Further therefore, very radically, that the rjasanensis zone probably corresponds to the greater part of the
Acknowledgement

This is a contribution to IGCP 506, under the leadership of Prof. Sha Jingeng.

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