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The Jurassic–Cretaceous boundary: problems of definition and procedure

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Problems with the Jurassic–Cretaceous (J–K) boundary are largely the result of stratigraphic difficulties caused by a lack of a significant faunal turnover at either boundary of the Berriasian stage, and to extreme faunal provincialism as a consequence of the Purbeckian regression. There is also a lack of agreement about basic principles of procedure, which could be resolved if we accept that system boundaries are conventional boundaries. The choice of boundary level depends primarily on its correlation potential. This would put an end to fruitless discussions about whether Berriasian faunas are Jurassic or Cretaceous. Continuity of usage is another important factor. For this reason the efforts of the International Working Group on the Jurassic–Cretaceous Boundary have been concentrated on the Tethyan–Boreal correlation of the Tithonian–Berriasian boundary, though so far with limited success. Other levels should be tested in future.

Another problem in inter-regional correlation is the lack of clarity in the underlying zonal concept. Fossil zones are traditionally biochronologic units based on evolutionary events. Therefore a clear distinction between biostratigraphic raw data and their biochronologic interpretation is absolutely necessary. System boundaries have to be defined by global boundary stratotype section and point (GSSP) according to the guidelines of the International Commission on Stratigraphy (ICS). This definition would normally start from a biochronologic marker level. It should be emphasized that only range zones, delimited by phyletic events, have unequivocal boundaries. Traditional ammonite zones (Oppel zones) are more loosely defined by their contents and have no clear cut boundaries. This should be taken into consideration when deriving the boundary definition from an ammonite zonation.

1. Introduction

According to the guidelines of the ICS (Cowie *et al.*, 1986), system boundaries have to be defined by a GSSP. Thus only when a boundary stratotype is agreed upon can the J–K boundary be definitely fixed. However, for various reasons we are still far from this goal.

The choice of the type section and the precise point in rock defining the system boundary has, according to the ICS guidelines, to be preceded by the choice of an appropriate boundary level. This means that the correlation potential of the boundary level has to be tested thoroughly before making a formal decision.

Egoian (pers. comm.) pointed out that there have been about a dozen meetings on the J–K boundary, none of them arriving at a solution to the problem. There are several reasons for this which may be summarized as follows:

(1) The J–K boundary does not correspond to an important faunal change, as do the Triassic–Jurassic and, above all, the Cretaceous–Paleogene boundaries.

(2) There has been much futile debate about the intrinsic nature of Berriasian faunas, whether they are more Jurassic or more Cretaceous in character.

(3) The J–K boundary was originally defined by the Purbeckian regression (see Gignoux, 1960, p. 422). This regression was a global event, resulting in very pronounced biogeographic provincialism during Tithonian–Volgian and Berriasian times.

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(4) It is generally agreed that fossils are the most important guide in Phanerozoic time correlation, but there is no consensus about the exact meaning of zones based on the stratigraphic distribution of fossils. It is often very difficult, therefore, to compare results from different authors, especially when raw data are not published together with their generalizations in terms of zones.

Before discussing these problems, it is useful to recall the recommendations made by the International Working Group on the Jurassic–Cretaceous Boundary at the 27th International Geological Congress in Moscow, 1984, which are as follows:

(1) the J–K boundary should be defined in marine facies in the Tethyan realm;

(2) the first candidate for the J–K boundary is the Tethyan Tithonian–Berriasian boundary, which corresponds to the base of a combined *Berriasella jacobi-Pseudosubplanites grandis* Zone, following the recommendation of the Colloque International sur la Limite Jurassique-Crétacé, Lyon-Neuchâtel (1975, p. 392);

(3) should it prove impossible to correlate this boundary level from the Tethyan and Boreal realm, another close to it would be preferred; the base of the *Tirnovella occitanica* Zone might be a good solution (Hoedemaeker, 1987);

(4) pending a final decision on the J–K boundary, the Berriasian should be placed in the Cretaceous. The term "Boreal Berriasian" should be used in order to make clear that its base probably does not correspond to that of the Tethyan type Berriasian.

The primary aim therefore would be to find a suitable marker species, preferably an ammonite, whose phyletic first appearance can be followed accurately over a great distance. So far, this ideal marker has not been found, and Tethyan-Boreal correlations close to the J-K boundary may differ by as much as two or three ammonite zones, as exemplified by the controversy between Jeletsky (1984) and Zeiss (1984, 1986). This discrepancy is in part the result of exceptional paleobiogeographic differentiation caused by the Purbeckian regression.

The confused state of the boundary resolution is also caused by differences in stratigraphic philosophy, which will probably never be entirely overcome. However, a common language is required so that data from different authors can be compared in detail.

2. Fundamental problems in establishing chronostratigraphic boundaries

2.1. *Natural or conventional boundaries*

There is a long tradition of making system boundaries coincide with major faunal turnovers, but an unequivocal boundary definition is only possible if we start from a single phyletic event. It is rather improbable that several species will appear or die out at exactly the same moment: a faunal turnover corresponds to a critical interval during evolution, with more extinctions and first appearances than usual in a given period. Placing a system boundary within such an interval has the advantage that auxiliary markers become available, which provide good approximations to the boundary where the primary marker is absent. But this practical aspect, though important for boundary recognition, is secondary in defining the boundary, which can only be based on a single marker, the choice of which is guided by practical considerations. In this sense, all chronostratigraphic boundaries are merely conventional boundaries. This statement has a direct bearing on the Cretaceous or Jurassic "nature" of the Berriasian stage. No major faunal turnover occurred at the Tithonian–Berriasian or Berriasian–Valanginian boundaries.

The prevailing usage since the beginning of this century has been to place the Berriasian within the Cretaceous. The difference in faunal changes between the upper and lower boundary of the Berriasian is obviously not so great that a majority of stratigraphers would abandon traditional usage. Under these circumstances the assignment of the Berriasian to either the Jurassic or Cretaceous depends upon which J–K boundary will have the better correlation potential. Nomenclatural stability is a major factor to be considered. Only if it would appear that a J–K boundary at, or near, the base of the Berriasian cannot be traced into the Boreal realm would another solution have to be adopted.

No positive results are available concerning the correlation of the *jacobi* and *occitanica* boundaries; thus the base of the *Fauriella boissieri* Zone and the Berriasian-Valanginian boundary (= base of the *Thurmanniceras otopeta* Zone, as proposed by Busnardo *et al.*, 1979) become possible candidates for the J–K boundary. If the choice between the latter two should become necessary, relative stability of nomenclature would be a strong argument to consider: a J–K boundary at the base of the *boissieri* Zone would force abandonment of the Berriasian stage or drastically alter its definition. This would not be the case if the J–K boundary is placed at the top of the Berriasian.

2.2. *Importance of regional zonations*

The starting point for inter-regional correlations and boundary definitions are, of course, regional zonations. Stray specimens of zonal markers or of other short-lived species may then be used to link different zonations. Kemper *et al.* (1981) gave an excellent demonstration of this method for the early Early Cretaceous. It should, however, be emphasized that the accuracy of this kind of inter-regional correlation depends heavily on the quality of regional zonations: well-founded and detailed zonations on both sides of the biogeographic boundary are a necessary prerequisite.

With respect to the J–K boundary, and in accordance with the recommendations quoted above, this means that we must try to follow the base of a Tethyan ammonite zone (preferably *jacobi* or *occitanica* Zone) into the Boreal realm. Should this be achieved (there appears to be little hope for the *jacobi* boundary), the base of the Cretaceous system would correspond to the base of a Tethyan ammonite zone in the Boreal realm. This would not, however, mean that Boreal ammonite zones would have to be dropped, since they would continue to provide the best means of correlation within the Boreal realm. Biostratigraphic time correlations will only be accurate if they are based on those marker species which are the most frequent in the region under study.

Regional correlations and the calibration of the underlying regional zones with inter-regional boundaries are two different problems which should be kept separate. Calibrations normally depend on rare occurrences of mixed faunas, and may be modified by later discoveries. This does not affect regional correlations. The same remark applies to the use of parallel zonations in the same region, which are based on different groups of fossils.

2.3. *Biochronologic zone concept*

It is crucial to clarify what kinds of zones and/or zonal boundaries are being used for correlation; a unified zone concept in biochronology is likely to prove elusive, but it should at least be possible for everyone to state clearly which type of zone is being used and which are the underlying raw data. This lack of information makes published interprovincial correlations difficult to analyse, especially for those who are not specialists in the group in question.

The nature of biostratigraphic boundaries: biostratigraphy versus biochronology. Direct correlation of first and last occurrences of a given species as observed in the field will result in diachronous boundaries, but all species have a limited life span: an order of magnitude of 1 Ma for Mesozoic ammonites is a realistic estimate. This means in practice that biostratigraphic boundaries of short-lived species are only to a limited extent diachronous. A maximum error of 1 Ma may not be too helpful in small scale mapping, but for Late Jurassic to Early Cretaceous intercontinental correlations, this is far beyond the precision of radiometric data. For all these reasons, the objective of biostratigraphy since Oppel's definitive work on zones has been to establish geological scales for time correlation.

Different types of biochronologic zones. Biochronologic interpretations are expressed in terms of zones, and it is here that problems start. Biochronologic zones are conceptual units: they are mostly extrapolations beyond what can actually be observed in the field. The observed stratigraphic range of a given species will often be less than its total life span. In other words, the chronozone (= life span) of a species has to be pieced together from local range zones. This synthesis will only be approximate, as are all scientific measurements, and because absolute precision does not exist, it is the margin of error that is important.

The problem can be well illustrated through calpionellid zones, which are based on outstandingly complete fossil documentation. There are some characteristic associations dominated by one genus (*Crassicollaria* Zone) or one species (*Calpionella* Zone using *C. alpina*). Although the transition from one association to the following may be rapid, it nevertheless takes a certain period. If zonal boundaries are to be unequivocally defined, they must correspond to one single event, preferably the phyletic first appearance of a marker species (in general first appearances provide more reliable data than extinctions). In some cases (see Remane, 1985, 1986) the phyletic origin of a species can be observed directly (e.g. *Tintinnopsella carpathica* at the base of the *Crassicollaria* Zone, *Calpionellopsis oblonga* at the base of the *oblonga* Subzone, and *Calpionellites darderi* at the base of the *Calpionellites* Zone).

This is the ideal case where biostratigraphic and biochronologic boundaries coincide. Such boundaries are not absolutely clear cut, but they are the most reliable: wherever the phyletic transition is visible, an isochron is reasonably inferred.

The base of the *Crassicollaria intermedia* Subzone (Remane *et al.*, 1986) is defined by the first appearance of *Calpionella alpina* whose direct ancestor is unknown. The base of the *Calpionellopsis* Zone provides another example of such an empiric boundary, which is clear cut, but approximate with respect to the phyletic first appearance of the marker species (*Calpionellopsis simplex*).

None of the calpionellid zones or subzones in current use (Remane *et al.*, 1986) corresponds to the life span of a marker species. This is quite natural because the extinction of one species will normally not coincide with the appearance of the next. Upper and lower boundaries of zones will thus be defined by different species. We deal with concurrent or successive range zones or interval zones, even if they are delimited in such a manner that they correspond closely to the range of a characteristic assemblage.

A limited number of richly fossiliferous successions would permit establishment of zones which give a good picture of the real succession of phyletic events. Where contradictory basic data exist, statistical methods may help to unravel the succession of events (see Gradstein *et al.*, 1985).

Theoretically the procedure outlined above could also be followed in setting up (biochronologic) ammonite zones. However, another zonal concept is often used here, because ammonites often show a discontinuous distribution, with fossiliferous beds separated by barren intervals. Furthermore, when Oppel (1856–1858) introduced the modern biochronologic zone concept, he based his zones on characteristic associations of more or less coeval ammonite species. The original Oppel zone is thus loosely defined by its contents, not by its boundaries. It may happen that the complete association is never present in one locality. In this sense Oppel zones, like all other biochronologic zones, are abstractions. They are separated by indeterminate intervals, as the exact succession of first and last appearances of the characteristic species is unknown. This may appear as a shortcoming of the concept, but with short-lived species, such as ammonites, it has the advantage that an Oppel zone can be determined quite accurately even in the absence of its index species or parts of the characteristic association. Far reaching and precise correlations can thus be made. Guex (1987) summarized a mathematically-based "unitary association", which he introduced earlier, as the smallest distinguishable biochronological unit, and Baumgartner (1984) applied this method to Middle Jurassic–Early Cretaceous radiolarians.

Zonal and system boundaries. It has been held that system boundaries should correspond to zonal boundaries, which is quite compatible with the GSSP concept (Cowie *et al.*, 1986). Boundaries of biochronologic range zones are defined by a phyletic event. The GSSP may easily be fixed to coincide with one of the best known biostratigraphic approximations of this event. The essential point is that the boundary definition, which has to be as precise as possible, starts from a sharp biochronologic boundary. Problems may arise, however, when Oppel zones are used which are more loosely defined by their contents. The best way to obtain a precise boundary through this approach would be to establish Guex's unitary associations instead of Oppel zones, where the boundary could be placed in the indeterminate interval between two unitary associations. The inherent indetermination of the boundary would thus be kept at a minimum level and, as unitary associations are more strictly defined than Oppel zones, the control would be better.

3. Recommendations for future work

On the basis of the theoretical considerations developed above, some concrete recommendations can be made for future work on the J–K boundary.

3.1. *Improve communications*

The preceding discussion emphasized the ambiguity of the term "zone". A meaningful discussion is possible only if all workers specify their zones with respect to the underlying biostratigraphic field data. In addition to the theoretical aspects, raw data should also be communicated, since different generalizations (i.e. abstractions and zonations) may be derived from the same raw data. This can be very important in judging alternative inter-regional correlations. Communicating raw data would also permit mathematical treatment, such as that described by Gradstein *et al.* (1985) or Guex (1987).

The exchange of information on different fossil groups between specialists should be improved. So far, this exchange has been mainly a question of correlation potential of the boundary level itself, but this also depends very largely on the presence or absence of other zonal boundaries close to the envisaged system boundary. These will ensure the possibility of making good approximations in the absence of the primary marker. But these zones will obviously be derived from other fossil groups; therefore the interdisciplinary dialogue between specialists of different groups is very important. As it is difficult to read the vast specialized literature outside one's own field, it is particularly important to have concise texts summarizing the relevant information. Casey *et al.* (1987) furnished an excellent overview of Boreal ammonite zones. A similar report on *Buchia* zones was published by Zakharov (1987). An agreement on calpionellid standard zones was attained by Allemann *et al.* (1971), with a further subdivision by Remane *et al.* (1986). The relevance of individual zonal boundaries for the J–K boundary has been discussed in detail by Remane (1986). Generalized information of this kind is still missing for Tethyan ammonites, radiolarians, ostracodes and nannoplankton.

3.2. *The need for more facts*

The inability to propose a reasonable J–K boundary level is not only a matter of insufficient communication. More data are required concerning the calibration of zones derived from different fossil groups and, above all, about mixed faunas which are so important for inter-regional correlation.

Besides classical biochronology, magnetostratigraphy has given most interesting results, and should be seriously considered in efforts to redefine the J–K boundary. Tethyan zonations, especially those based on calpionellids and nannoplankton, are already quite well calibrated with magnetic reversals (Ogg & Lowrie, 1986; Channel & Grandesso, 1987; Ogg *et al.*, 1991).

Ogg & Lowrie (1986) proposed a J–K boundary definition using the base of polarity chron CM18, which corresponds approximately to the base of the *Calpionella* Zone. As a matter of principle it seems acceptable to tie a system boundary to a magnetic reversal, but the choice of a specific level was premature. Magnetic reversals can as yet only be located with the help of fossil markers, or by general position in the case of pelagic successions with near constant rates of sedimentation. So far, no useful magnetic reversal candidates for a boundary have been forthcoming from the Boreal realm.

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