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Definition of the Triassic-Jurassic boundary

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Abstract - The criterion for definition of the Triassic-Jurassic boundary should be a marker event of optimal global correlateability. Only an ammonite event meets this criterion, and the lowest occurrence of *Psiloceras tilmanni* in the New York Canyon area of Nevada, USA provides the most globally correlateable datum. Other potential marker events for definition of the Triassic-Jurassic boundary (bivalve, conodont and radiolarian bio-events, mass extinction and a carbon isotope excursion) have less correlation potential.

Introduction

As the time for selection of a GSSP for the Triassic-Jurassic system boundary (TJB, base of Hettangian stage) approaches (Fig. 1), there is a need to discuss the criterion for definition of the boundary. Since the 1960's, the LO (lowest occurrence) of the ammonite *Psiloceras* (usually the species *P. planorbis*) has provided the working definition of the TJB (e.g., Lloyd, 1964; Maubeuge, 1964; Cope et al., 1980; Warrington et al., 1994; Gradstein et al., 2004). However, rather recently, other criteria for boundary definition have been advocated. These include a change in the bivalve fauna (essentially the LO of *Agerchlamys*), a sudden negative excursion of carbon isotopes and the LO of *Psiloceras tilmanni*, which precedes the LO of *P. planorbis*. Other criteria that have been or can be advocated include the supposed TJB mass extinction, the HO (highest occurrence) of conodonts or a significant evolutionary turnover of radiolarians.

What must underlie discussion of the definition of the TJB is the well accepted concept that global correlateability should be the main emphasis in the selection of a GSSP (e.g., Cowie et al., 1986; Remane et al., 1996; Gradstein et al., 2004; Walsh et al., 2004). As Remane et al. (1996: 79) expressed it, "the boundary definition will normally start from the identification of a level which can be characterised by a marker event of optimal correlation potential." Thus, our goal here is to evaluate the possible marker events that could be used to define the TJB and to argue that an ammonite-based marker event has optimal correlation potential. This marker event is the LO of *Psiloceras tilmanni* in the New York Canyon section of Nevada.

Ammonite criteria

Distinction of the Triassic and Jurassic systems in marine biostratigraphy has a long tradition rooted in ammonite biostratigraphy. This is because the ceratite-dominated ammonite faunas of the Triassic virtually disappeared across the system boundary and were totally replaced by the smooth-shelled psiloceratids of the Early Jurassic. Because of the long history of study of this ammonite turnover, its details are extremely well documented on a global scale, especially in western North America, South America and Western Europe. This ammonite turnover thus provides wide-ranging correlations that are intensively studied, extensively published and documented. No other bio-event associated with the TJB can claim such investigation, and no bio-event is comparable to the ammonite turnover to provide a *globally correlateable* criterion for boundary definition.

The most complete and completely known succession of ammonites across the TJB is in the New York Canyon area of western Nevada, USA (Fig. 1) (e.g., Taylor et al., 2000; Guex et al., 2004). This succession presents two possible choices of an ammonite marker event: (1) the LO of the psiloceratid *P. tilmanni*, the stratigraphically lowest smooth-walled psiloceratid; or 2) the LO of *P. pacificum* and other entirely smooth walled psiloceratids (Fig. 2).

Using the LO of *Psiloceras tilmanni* as the boundary marker event has the advantage that it would place all the smooth-shelled psiloceratids in the Jurassic, a concept long adhered to by paleontologists who study ammonites. Furthermore, Bloos (2004) has noted that the LO of *P.*

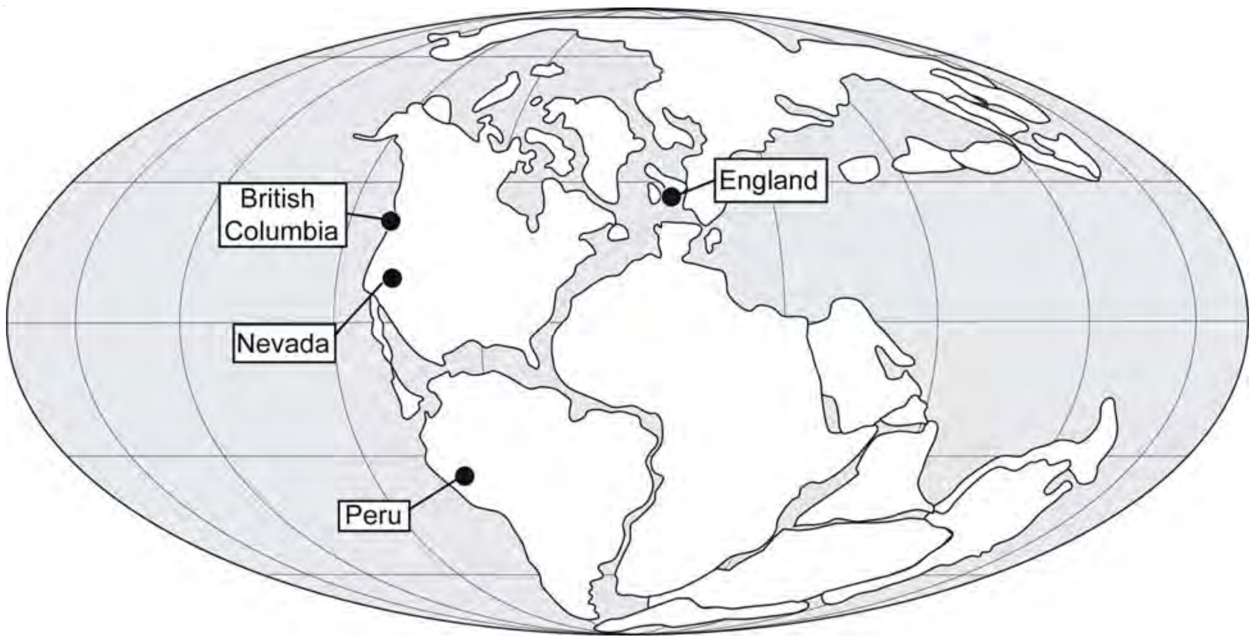

Figure 1. Late Triassic paleogeographic map showing location of the four candidates for a GSSP of the Triassic-Jurassic boundary (base of Hettangian). They are: Queen Charlotte Islands, British Columbia, Canada; New York Canyon area, Nevada, USA; Utcubamba Valley, Peru; and St. Audrie's Bay, England.

tilmanni is only slightly younger than most of the other criteria used to identify the TJB, such as the extinction of typical Triassic taxa of ammonites and bivalves and the HO of Conodonta (Fig. 2). For example, in the New York Canyon area, the HO of *Choristoceras marshi*, a widely distributed terminal Triassic ammonite, is only a few meters below the LO of *P. tilmanni*. This means that in strata that lack *Psiloceras tilmanni*, these other criteria can act as proxies for placement of the TJB.

In the New York Canyon area, the LO of *Psiloceras pacificum* is stratigraphically higher than the LO of *P. tilmanni*, so it does not as closely approximate those proxies that can be used to identify the TJB. The LO of *P. planorbis* also is higher than the LO of *P. tilmanni*, and it might approximate the LO of *P. pacificum*, though this is uncertain. Continued definition of the TJB by the LO of *P. planorbis* (or equating it to the LO of *P. pacificum*) thus defines a boundary farther removed from the other bioevents that are proxies for identifying the TJB than does a TJB boundary defined by the LO of *P. tilmanni* (Fig. 2).

Claims that the LO of *Psiloceras planorbis* (or of any other *Psiloceras* species) are not useful for TJB definition because of the diachroneity of the LO of *P. planorbis* in Western Europoe (e.g., Hesselbo et al., 2002) are based on a lack of conceptual and methodological understanding of how boundaries are defined. The LO of *P. planorbis* is diachronous in Western Europe largely because of the lack of open marine facies across the TJB boundary. Furthermore, older *Psiloceras* (such as *P. tilmanni*) are known elsewhere. The LO of *P. tilmanni* at a single place (the GSSP) can be used to define the TJB. If the LO of *P. tilmanni* elsewhere is shown not to be the same age as at the GSSP, this will introduce some imprecision into using *only* the LO of *P. tilmanni* to identify the TJB, but it will not change the definition of the TJB. Clearly, no species of organism had an instantaneous appearance globally, so we should expect some diachroneity in the LO of any index fossil when viewed over a broad enough geographic area.

Using the LO of *Psiloceras tilmanni* as the marker event for definition of the TJB thus has these advantages: (1) it maintains longstanding tradition of placing the boundary so that all smooth-shelled psiloceratids are Jurassic; (2) it is a boundary above all bio-events traditionally considered Triassic; (3) it provides an ammonite-based definition of broad correlation potential (*P. tilmanni* has a distribution from Nevada to Chile); and (4) it places the boundary close to (just above) other marker events that can be used to identify the TJB in sections that lack ammonites. The LO of *P. tilmanni* thus defines a TJB of optimal correlation potential.

Bivalves

Hallam (1981) first proposed the idea of a major change in the marine bivalve fauna across the TJB. However, the idea of using a bivalve criterion to identify the boundary is very recent (McRoberts, 2004). It is largely based on a change in the bivalve fauna approximated by the LO of *Agerchlamys* at New York Canyon, which occurs just above the beginning of the negative carbon isotope excursion (Guex et al., 2004, fig. 1, bed N3). According to McRoberts (pers. commun., 2004), the LO of *Agerchlamys* at New York Canyon is an immigration event. If so, then

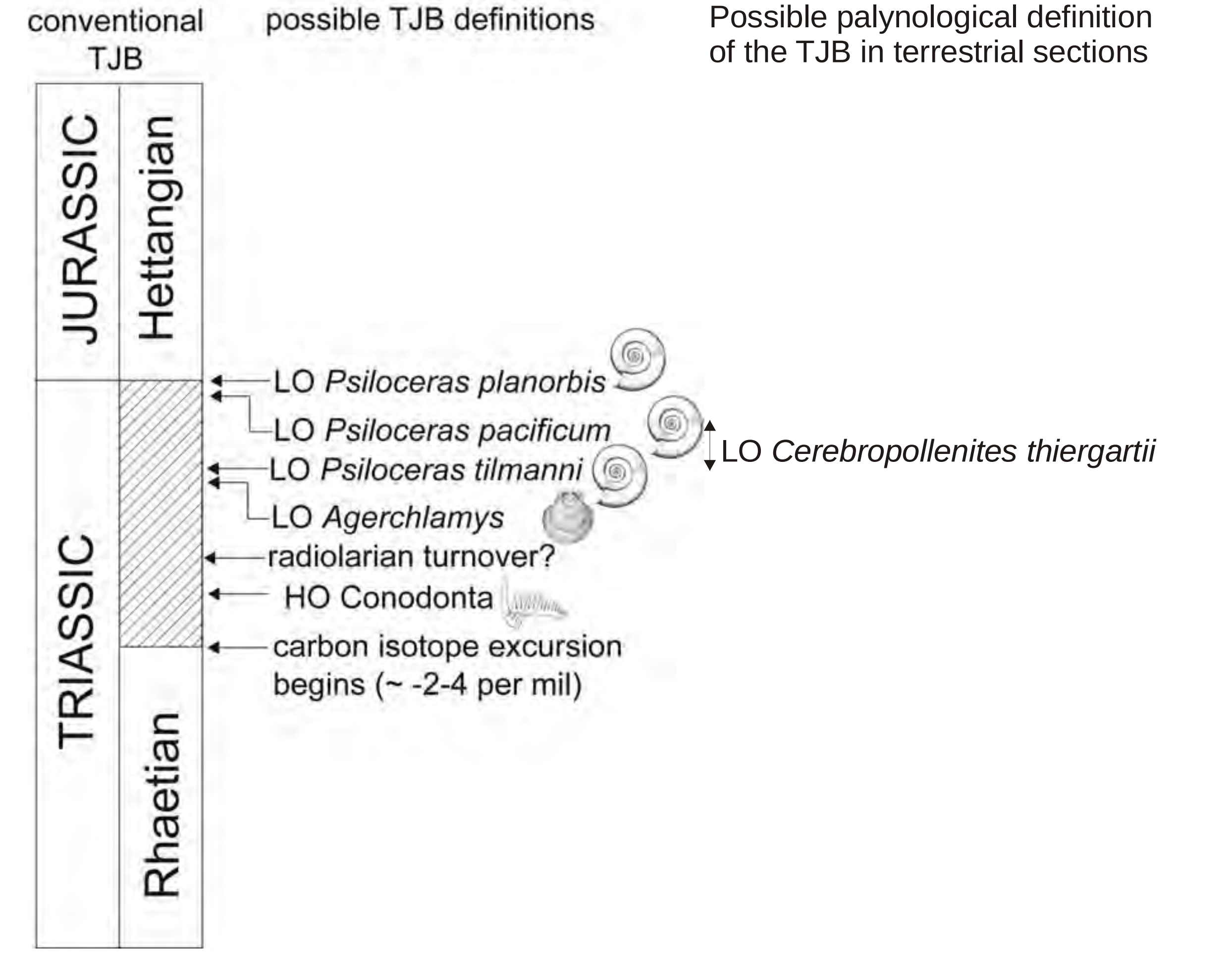

Figure 2. Succession of potential marker events for definition of the Triassic-Jurassic boundary. Succession is based primarily on New York Canyon area, so exact position of radiolarian turnover is uncertain. The LO's of *P. pacificum* and *P. planorbis* may be equivalent, but this is uncertain.

this LO is diachronous, as is the LO of any organism viewed globally.

McRoberts (2004) stated that the bivalve change coincides with a negative excursion of carbon isotopes, but at New York Canyon the isotope excursion begins just before the bivalve change (Guex et al., 2004). The bivalve criterion for TJB definition is little studied and tested, so it lacks extensive documentation. Until it is well documented, its potential for global correlation remains uncertain. However, the LO's of *Agerchlamys* and *Psiloceras tilmanni* in the New York Canyon area are only a few meters apart, and this means that the bivalve change provides another useful proxy for correlation of a TJB defined by the LO of *P. tilmanni*.

Conodont HO

To our knowledge, nobody has formally advocated using the HO of Conodonta to define the TJB, even though the extinction of Conodonta has long been seen as a terminal Triassic event, and the presence/absence of conodonts thus is routinely used to distinguish Triassic from Jurassic strata. Rhaetian conodont assemblages are of low diversity and abundance, and conodonts can be easily reworked. Therefore, the HO of Conodonta is not a reliable criterion for TJB definition. However, it is very useful to know that the presence of autochthonous Conodonta is a pre-Jurassic indicator, and this micropaleontological criterion has been widely used and accepted. So, defining the TJB at a level below the conodont HO is not desireable.

Radiolarians

Data from the Queen Charlotte Islands in western Canada (Fig. 1) have been interpreted to indicate a drastic extinction of radiolarians at the TJB (Tipper et al., 1994; Carter, 1994; Ward et al., 2001). Carter (1994) cites the loss of 45 radiolarian species in the top 1.5 m of the *Globolaxtorum tozeri* zone (topmost Rhaetian) on Kunga Island, above which is a low diversity Hettangian fauna in which nasselarians are rare. The radiolarian change as currently understood does not represent a globally correlateable event, though it has recently been identified in Japan. Nevertheless, it is very close in age to the LO of *Psiloceras tilmanni* (Fig. 2) and thus provides another proxy for correlation of a TJB defined by the LO of *P. tilmanni*.

Mass extinction

If there is a mass extinction in the TJB interval, why not use the extinction as a datum to define the TJB? Hallam (1990) advocated this, but there is no single mass extinction at or near the TJB (Hallam, 2002; Tanner et al., 2004; Lucas & Tanner, 2004). Instead, there are a series of extinctions, some local, others global, during the Triassic-Jurassic transition – which extinction should be chosen? A mass extinction criterion for TJB definition thus is problematic simply because no single mass extinction has been identified.

Carbon isotope excursion

Hesselbo et al. (2002, 2004) advocated using a carbon isotope excursion to define the TJB. This is a negative excursion of ~ 2-4 per mil of organic carbon seen in the St. Audries Bay section in England (Fig. 1). It is stratigraphically below the conodont HO (Fig. 2), and apparently correlative isotope excursions at New York Canyon and in the Queen Charlotte Islands are also in Rhaetian strata (Guex et al., 2004; Ward et al., 2004). The isotope excursion is thus at a level always considered Late Triassic by any biostratigraphic criterion.

A serious drawback to using an isotope excursion to define the TJB is that it needs to be associated with a biostratigraphic datum. As Remane et al. (1996:79) noted, "geophysical and geochemical events are, however, repetitive, and do not allow an unequivocal determination of the age. They need calibration through radioisotopic or biostratigraphic dating." The datum that corresponds to the Late Triassic isotope excursion in some sections according to McRoberts (2004) is a bivalve change, so the drawbacks of using that change to define the TJB (see above) apply here.

The isotope excursion has additional problems. Thus, despite its apparent widespread consistency, note that the isotope record for the upper Rhaetian through lower Hettangian displays complexities that vary from section to section; therefore, application of the isotope excursion as a non-biostratigraphic marker is not straightforward. Serious questions can be raised about the relative contributions of terrestrial vs. marine organic components in sections characterized by significant changes in sea level and facies (such as St. Audrie's Bay), and these questions have not been addressed sufficiently. Differences in accumulation rates within and between sections complicate the shape of the isotope excursion curve and the ability to correlate it reliably.

Therefore, the isotope excursion is not a desireable marker event for TJB definition because: (1) it begins at a stratigraphic level always considered Rhaetian, and thus predates the HO of Conodonta and many other bio-events long considered Triassic; (2) it is not a unique event and can only be identified uniquely by its association with a biostratigraphic datum; and (3) the excursion itself is complex and still relatively untested.

Palynology

One of the problems in a palynological definition of the base of the Jurassic in a terrestrial setting is that there are no major palynofloral breaks that could be correlated precisely with the Triassic-Jurassic boundary (Fisher and Dunay, 1981; Hounslow et al., 2004, Kuerschner et al., sub.). The exact stratigraphic age of the microfloral event in the Newark basin is uncertain (Hounslow et al., 2004; Kuerschner et al., sub.). The only morphologically distinct post Triassic taxa, which occur in the *planorbis* beds of the British Rhaeto-Liassic are *Cerebropollenites macroverrucosus* and *C. thiergartii* (Fisher and Dunay, 1981). In the British Rhaetian – Liassic sections, *C. thiergatii* has its FO at the base of the *planorbis* beds, whereas *C. macroverrucosus* has its FO date in the upper part of the *planorbis* beds. New data (Kuerschner et al., sub.) from the Tiefengraben section in the Northern Calcareous Alps (Austria) show, that *C. thiergartii* enters the record in the Tiefengraben Mb. (=pre-planorbis beds), within the lower part of the main negative isotope excursion, 8m below of the FO of the first Jurassic ammonite *P. calliphyllum*. The first occurrence of *C. thiergartii* approximately coincides with the base of the Hettangian as it would be defined by ammonites. Therefore it may become useful for a correlation of the base of the Jurassic between terrestrial and marine sections.

Conclusions

The best definition of the TJB will permit precise global correlation. Although no criterion may be ideal, ammonite-based definitions have the advantage of long-term study, testing and documentation. Indeed, for more than a century, the TJB has been defined by an ammonite event, and no other criterion comes close to providing an event of optimal global correlation potential. By that criterion, the LO of *Psiloceras tilmanni* in the New York Canyon area of Nevada appears to be the best marker event for TJB definition.

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