A proposal for the base Hettangian Stage (= base Jurassic System) GSSP at New York Canyon (Nevada, USA) using carbon isotopes

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Abstract It is here proposed that the Global Stratotype Section and Point (GSSP) for the basal boundary of the Hettangian Stage of the Jurassic System be defined at the peak of the first negative Carbon Isotope Excursion (CIE). The peak CIE occurs within a brownish grey, laminated, muddy siltstone, approximately 8m above the base of the Muller Canyon Member of the Gabbs Formation in the Ferguson Hill section within New York Canyon, Nevada, USA. [N 38°29'10.68", W 118°05'00.72"]. See Figure 1a-c for location and outcrop photographs. This isotopic event is closely associated with secondary biostratigraphic markers, including the FODs of the bivalve *Agerchlamys boellingi* (1.6m above the isotopic event) and ammonoids of the *Psiloceras tilmanni* group (2.6m above the isotopic event).

1. Introduction

The Ferguson Hill section in New York Canyon has been well studied and is the subject of numerous papers describing in detail the stratigraphy, paleontology, and geochemistry (*e.g.* Muller & Ferguson, 1939; Taylor *et al.*, 1983, 2000; Guex *et al.*, 1997, 2003a, b; Ward *et al.*, 2007). This section was first proposed by Guex *et al.* (1997) as a candidate GSSP for the Triassic–Jurassic boundary, and the most recent proposal (Lucas *et al.*, 2005) advocated the first occurrence of smooth ammonoids of the *Psiloceras tilmanni* group at Ferguson Hill as the defining criteria for the base Hettangian GSSP.

As discussed elsewhere (*e.g.* Guex *et al.*, 1997; Lucas *et al.*, 2005; and see also Warrington, 2003), the Ferguson Hill section arguably represents the most complete of known marine Triassic-Jurassic boundary successions with an abundance of shallow-water fossils. This attribute, along with the favourable facies for widespread correlation, fulfill the main requirements of a GSSP of continuous sedimentation in a marine environment (Cowie *et al.*, 1986; Remane *et al.*, 1996). Perhaps most significant is that the defining criterion, the peak initial CIE, offers the most robust datum for correlation in more boundary sequences than other potential biostratigraphic defining criteria and thereby fulfills the "correlation precedes definition" philosophy in GSSP selection as discussed by Remane *et al.* (1996). Furthermore, this section is easily accessible and has already received the guarantee of permanent protected status should it be selected for the GSSP (see Warrington, 2003).

Stratigraphic measurements and biostratigraphic positions mentioned herein are taken from Ward *et al.* (2007) and differ somewhat from those previously published by Taylor & Guex (2002) and Guex *et al.* (2003a, b, 2004). Ward *et al.* (2007) suggested that the differences between their dataset and that of Guex *et al.* (2003a, b, 2004), particularly with regard to the stratigraphic thickness of the strata studied, may be due to the gradational nature of the lithostratigraphic transitions and different definitions of the lower and upper boundary of the Muller Canyon Member. Both the underlying contact with the Mount Hyatt Member, and the overlying contact with the Sunrise Formation, are gradational in facies, comprising limestone and siltstone interbeds. Additionally, Ward and others measured the section approximately 25m to the northeast of the Guex *et al.* section and may have therefore captured lateral differences in stratal thickness. Guex (pers. comm., 2006) has argued that a small fault, low in the section (below the CIE), may have been overlooked by the Ward *et al.* team. Irrespective of a missed fault of minor consequence, or differences in definition of member contacts, *the relative sequence of events (both isotopic and bioevents) are essentially the same between the two sets of measurements.*

As with all other proposed candidate GSSP sections for the base-Hettangian (St. Audrie's Bay, England; Kunga Island, Canada; Kuhjoch, Austria), the Ferguson Hill section does have a few drawbacks. To date, apart from recently discovered Rhaetian conodont elements belonging to *Misikella* and *Zieglericonus* and as yet unidentified radiolarians in the Mount Hyatt Member (M. Orchard, pers. comm., 2006), no significant microfossils have been reported from the Ferguson Hill Triassic–Jurassic succession. Additionally, the strata in the New York Canyon area, including the section at Ferguson Hill, have been thermally altered, and early attempts to recover a primary remnant magnetic signal have been without success (see Warrington, 2003). In spite of these limitations, we concur with Guex *et al.* (1997) and Lucas *et al.* (2005) that the Ferguson Hill section represents the best available stratigraphic succession to define the boundary.

2. Choice of CIE criterion and precedent

As described in Ward *et al.* (2007), and shown in Figure 1, the $\delta^{13}C_{org}$ profile at Ferguson Hill has a nearly con-

stant value of -28.6‰ VPDB through the upper Mt. Hyatt Member and the first 7.8m of the Muller Canyon Member. Between 7.8m and 9.0m above the base of the Muller Canyon Member, $\delta^{13}C_{org}$ drops steadily to -29.8‰ VPDB marking the initial CIE that peaks at 8.0m. The $\delta^{13}C_{org}$ values then increase steadily to -27.3‰ VPDB at 18.5m, marking the positive excursion, and finally drop to -29.1‰ VPDB at 25m, representing the beginning of the second, broader negative swing. At Ferguson Hill, the initial negative CIE is clearly delineated by a series of seven data points.

Of the three potential data based on geometric inflections of the CIE shown in Figure 2, the choice of the peak initial negative isotope excursion (level B in Figure 2) is primarily based upon the fact that it is an apparently short-lived correlatable event that can be most easily recognized with respect to adjacent segments of the C-isotopic curve that are either strongly positive or, as in the second negative swing, known to have a much longer duration and broader inflection. The alternative datum (level A in Figure 2) also presents a potentially suitable horizon, but is not as easily correlated to other sections, especially those in Alpine Europe, where the strata above the 'event horizon' and below the initial peak negative CIE are either highly condensed or have a demonstrable stratigraphic gap. The highest potential isotopic datum (level C in Figure 2) is deemed unsuitable, in that it is represented by a much broader inflection of $\delta^{13}C_{org}$ values, passing into rather consistently negative values (-29.1‰ VPDB) and therefore more difficult to recognize. Furthermore, and perhaps more importantly, this second excursion occurs above a secondary biostratigraphic marker — the FOD of *Psiloceras tilmanni* group ammonoids.

Lucas *et al.* (2005) have raised two primary objections to choosing a carbon isotope excursion as a GSSP defining criterion for the base Hettangian: (1) geochemical events are not unique, and (2) recognition of CIE geometry is dependent on sedimentation rates and environmental factors, such as the proportion of terrestrial *versus* marine organic carbon input. While this may be true, in the general sense that geochemical anomalies are not unique and that the shape of any geochemical profile is dependant on a host of depositional and paleoenvironmental processes and their rates, when considered along with the adjacent 'background' segments of the isotope profile, such excursions, especially such large ones as observed at the Triassic–Jurassic boundary interval (which average around -3.5‰ VPDB in organic matter) can be easily recognized and correlated, provided geochemical sampling is of sufficient stratigraphic density (*i.e.* not based on a single point; see for example de Wit *et al.*, 2002 for a discussion on the isotopic event with respect to the Permian–Triassic boundary). An independent assessment of the utility of the CIE as the defining criterion can be made by comparison of sections representing different marine facies with different depositional rates (Figure 3, and see discussion below in correlation section).

There is a precedent in choosing a negative carbon isotope excursion as a GSSP datum. The base Eocene (= base Ypresian) GSSP was selected in 2002 and ratified by the IUGS in 2003 to be the base of the significant negative carbon isotope excursion in the Gabal Dababiya section in Egypt (Aubry & Ouda, 2003). This isotopic event is closely associated with secondary biostratigraphic markers, including the FODs of the nannoplankton *Discoaster anartios* (2.3m above the isotopic event) and the foraminifers *Acarinina sibaiyaensis* and *Acarinina africana* (2.5m above the isotopic event).

In addition to the base Eocene CIE datum described above, other non-biostratigraphic events have been selected as primary defining criteria in the selection of GSSPs. For example, the base Paleocene (= base Danian) is defined by the iridium spike associated with Cretaceous-Paleogene mass extinction (*e.g.* Bensalem, 2002), and the base of the Miocene (= base Aquitanian) is defined as the base of magnetic polarity Chron C6Cn.2 (Steiniger *et al.*, 1997). It can be argued that these defining criteria are, like a CIE, non-unique events that are, however, easily recognized within the context of adjacent segments of their geochemical or magnetic polarity scales.

3. Associated bioevents

The boundary interval at Ferguson Hill contains both ammonoids and bivalves that may serve as secondary biostratigraphic markers closely associated with the proposed CIE GSSP defining datum (Figures 1, 2). Both bivalve and ammonoid associated bioevents occur slightly above (between 1.6 and 2.5m) the CIE and are of a comparable stratigraphic distance from the proposed GSSP as the secondary bioevents for the base Eocene. A brief discussion of both associated bioevents follows below.

3.1 Ammonoids

At the Ferguson Hill section, the initial negative isotope excursion is within the 10.5m-thick interval between typical Triassic ammonoids (*e.g. Choristoceras crickmayi*), within the topmost Mt. Hyatt Member of the Gabbs Formation, and ammonoids considered to be of 'Jurassic' affinity (*e.g.* species of the *Psiloceras tilmanni* group), within the upper part of the Muller Canyon Member of the Gabbs Formation. At the Ferguson Hill section, the FOD of *Psiloceras tilmanni* group ammonoids occur at 10.5m above the base of the Muller Canyon Member and 2.5m above CIE datum. Systematic descriptions of the psiloceratid ammonoids can be found in Guex (2003b).

Ammonoids of the *Psiloceras tilmanni* group are currently known to occur in only three regions: (1) New York Canyon Nevada (*e.g.* Guex *et al.*, 2003a), (2) Utubamba Valley, Peru (*e.g.* Hillebrandt, 1994), and (3) Tirol, Austria (Hillebrandt *et al.*, in prep). However, apart from the Peru material and newly discovered specimens from the Kuhjoch section in Tirol Austria, these ammonoids are
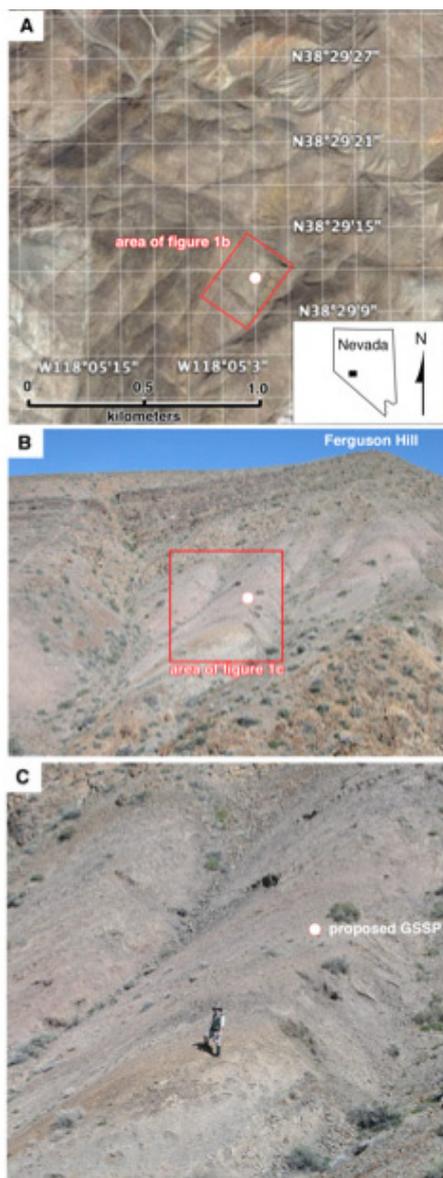
Figure 1: Location and position of proposed GSSP. **A**) Aerial photo of New York Canyon and Muller Canyon region (modified from Google Earth image). **B**) Outcrop photo of SE face of Ferguson Hill. **C**) Detail of Muller Canyon Member of Gabbs Formation showing position of proposed GSSP

represented by crushed specimens in which sutures are not preserved, therefore precluding definitive species identification.

Furthermore, based on the best available data, the first occurrences of *P. tilmanni* group ammonoids can demonstrably be shown to occur at different stratigraphic levels, and, where data are known, they occur at different positions relative to the carbon isotope curve (Krystyn, pers. comm., 2006; Krystyn *et al*., 2005; see also discussion in Bloos, 2006). In fact, Bloos (2006, p.7) notes that "the earliest *Psiloceras* are extremely rare in most parts of the world, proxies are generally needed for correlation". It should be noted that, should ammonoids of the *P. tilmanni* group be selected as a defining criterion, one would have to rely on proxies in more instances than with the

CIE criterion that is now known from more than 10 stratigraphic sections.

A further major detriment to choosing the FOD of ammonoids of the *Psiloceras tilmanni* group at Ferguson Hill is that these ammonoids are not part of an evolutionary series in which any potential ancestor is known. As such, *P. tilmanni* group ammonoids do not represent an ideal choice for defining the base Hettangian GSSP, but they may serve as a close proxy to a CIE defined datum.

3.2 Bivalves

The initial negative isotope excursion is more closely associated with the FOD of pectinacean bivalves. At Ferguson Hill, the FOD of *Agerchlamys boellingi* occurs at 9.6m above the base of the Muller Canyon Member and 1.6m above the CIE datum. The systematic description of *Agerchlamys boellingi* (type locality: Reno Draw section, New York Canyon) is by Taylor & Guex (2002).

The bivalve *Agerchlamys boellingi* is known from several sections in North America at similar, or slightly higher, stratigraphic levels, but never from undisputed Triassic strata. McRoberts (2004) discussed well-preserved representatives of this species from several sections spanning the Triassic–Jurassic boundary interval in northeastern British Columbia. In these localities (*e.g*. Ne Parle Pas Point, Black Bear Ridge and Crying Girl Prairie), *Agerchlamys* first occurs within 1m above the youngest undisputed Triassic strata and approximately 0.2 -3.0m below psiloceratid ammonoids. Recent work in Austria (McRoberts field work, 2006) documented similar bivalves, often identified as '*Chlamys textoria*' (see, for example, Golebiowski & Braunstein, 1988) as first occurring in greater abundance within 0.2–3.0m above the CIE in many alpine sections, including Kendlebachgraben, Tiefengraben, Kuhjoch, Schlossgraben and Steinplatte (Kammerker and Möseralm sections).

As with the ammonoids of the *Psiloceras tilmanni* group discussed above, neither *Agerchlamys boellingi* nor '*Chlamys textoria*' are part of a demonstrable evolutionary series in which potential ancestors are known, and therefore they are not suitable for defining a datum for the base Hettangian GSSP. The original definition of *Agerchlamys* by Damborenea (1993) only lists three included species, of which two (the type *Agerchlamys wunchae* and *Agerchlamys proprius*) are Jurassic. The one Triassic species listed by Damborenea (1993, 2002) as belonging to this genus was originally described as *Chlamys (Camptochlamys) inspecta* Kiparisova (*in* Kiparisova *et al*., 1966) from the Carnian and Norian of Siberia. This species lacks radial ornament on its auricles and is here considered to be distinct from, but closely related to, *Agerchlamys*.

4. Correlation potential

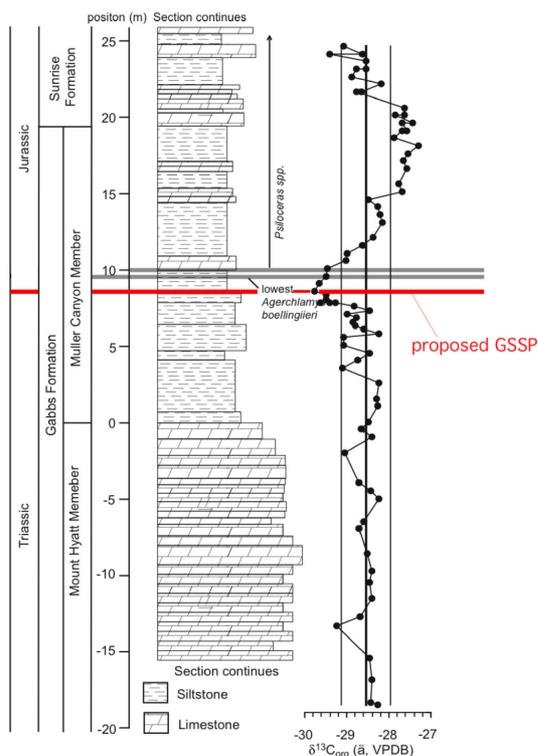As recognized by many authorities (*e.g*. Kump & Arthur, 1999; see also Beerling & Berner, 2002), perturbations in

Figure 2: Lithostratigraphy, biostratigraphy and δ¹³C$_{org}$ profile, Ferguson Hill section (New York Canyon, Nevada, USA), showing proposed GSSP (modified from Ward *et al*., 2007)

the Earth's carbon cycle represent geologically instantaneous events (<5kyr), are of global scale, and can be (or potentially can be) observed in marine and continental settings in a variety of facies (*e.g.* deep-water marine clastic, shallow-water carbonate platform, terrestrial paleosols, lacustrine deposits, *etc*.). Such large CIEs have been repeatedly used as correlation data for many stage boundaries, including the Permian-Triassic boundary (*e.g.* Payne *et al*., 2004), Cenomanian-Turonian boundary (*e.g.* Sageman *et al*., 2006), and perhaps most relevant, the base of the Eocene (*e.g.* Aubry & Ouda, 2003).

The CIE in the Triassic-Jurassic boundary interval is now known from many localities from several continents, from low to mid paleolatitudes, and provides a robust and reproducible correlation datum. The CIE is well documented at several other GSSP candidates, including St. Audrie's Bay, England (Hesselbo *et al*., 2002), Queen Charlotte Islands, British Columbia (Ward *et al*., 2001, 2004; Williford *et al*., 2007), and numerous sites in Austria, including the Kendlebachgraben and Tiefengraben sections (Kuerschner *et al*., 2007) and the newly proposed Kuhjoch/Hinterriss section (Hillebrandt *et al*., in prep.; Kuerschner, pers. comm.). Other Triassic-Jurassic boundary sections in which a carbon-isotope excursion has been identified (*e.g.* McRoberts *et al*., 1997; McElwain *et al*., 1999; Pálfy *et al*., 2001; Galli *et al*., 2005) have generally coarser sampling density, or have known stratigraphic gaps precluding the unambiguous identification of the two-fold negative excursion

geometry.

The geometry of the Triassic-Jurassic CIE can be identified irrespective of water depth and depositional rates. For example, the initial CIE at St. Audrie's Bay, Portovenere (Italy) and those from Tirol (Austria) (see Figure 3), arguably the most shallow and condensed sections where the initial CIE is constrained within 1–5m, can be easily correlated to the Kennecott Point section, where the initial CIE is contained within more than 10m of radiolarian-bearing, deep-marine carbonate-bearing siltstone and shale, representing an order of magnitude difference in sedimentation rates. The consistent geometry of the two-fold carbon isotope excursion in both condensed and expanded sedimentary sequences and its position relative to all known biostratigraphic markers is consistent from such widespread regions as the northwestern European seaway and along the western margin of Pangea, provides strong evidence that the isotope event was synchronous and global in scale.

In all of the aforementioned sections, and all others in which the CIE is recognized (*e.g.* both published and unpublished sections in Austria and Italy, elsewhere in North America), the peak of the initial CIE occurs above the primary extinction 'event' horizon, delineated by the loss of marine macrofauna, especially bivalves, radiolarians, gastropods, brachiopods and, in some places, corals. This 'event horizon' also marks the last occurrence of Rhaetian index ammonoid *Choristoceras marshi*. However, some fossil groups, particularly pollen and spores (but also some foraminifers) apparently show a delayed turnover several meters above the CIE (*e.g.* Ergelijk *et al*., 2004; Kuerschner *et al*., 2007; Hillebrandt *et al*., in prep.). Not surprising, however, is that even though the significant taxonomic change in pollen and spores occurs above the main extinction horizon, the strata containing the initial CIE are typified by a dominance/abundance of opportunist palynoflora taxa, such as *Corollina* and fern spores. Additionally, rare con-
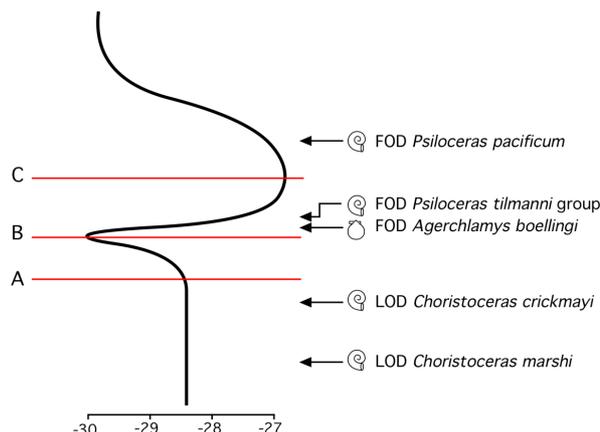

Figure 3: Idealized C-isotope profile and associated important biomarkers from the Ferguson Hill section at New York Canyon. Levels A, B and C indicate potential GSSP-defining criteria, based upon inflections of the C-isotope curve. Level B (peak negative excursion) is the favored GSSP criterion in this proposal. *NB* No vertical scale is implied (see Figure 1 for absolute position)
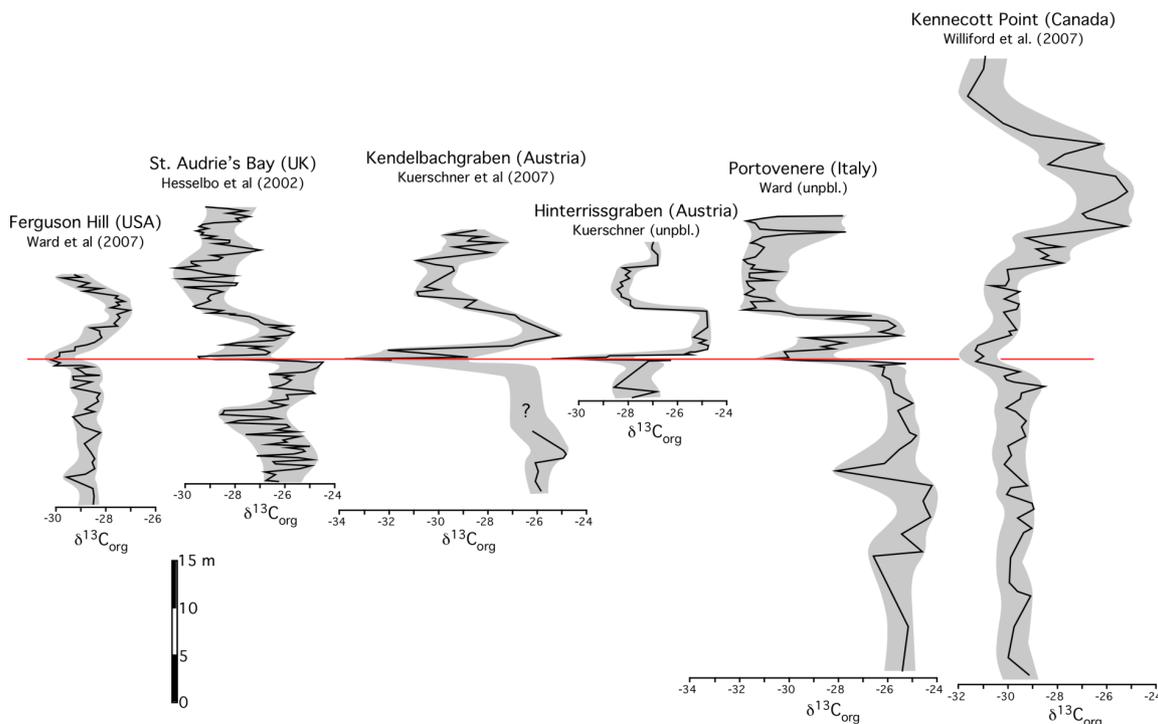
Figure 4: Correlation of C-isotope profiles from North America and Europe. Note that the primary defining criterion for the proposed GSSP is the peak of the initial C-isotope excursion (CIE), indicated by the red line

odonts may range up several meters into the overlying strata above the initial CIE in England and Hungary (Heinz Kozur, pers. comm., 2005; Pálfy *et al*., 2001; see discussion in Hesselbo *et al*., 2004).

To date, the carbon isotope excursion has not yet been reported from South America, where potential boundary sections (*e.g.* Chilingote, Peru) containing *Psiloceras tilmanni* ammonoids are known to occur, nor is it known from other regions, such as New Zealand or Asia. In these regions, and in other areas where post-depositional changes in carbon isotopic composition precludes accurate geochemical analyses, secondary biostratigraphic markers, *e.g.* the FOD of smooth psiloceratid ammonoids, can be used as proxies for recognizing the base Hettangian.

5. Conclusions

A defining criterion for the base Hettangian GSSP at the peak of the first negative Carbon Isotope Excursion represents the best available choice, among alternative biologic or geochemical events. Although somewhat below a traditional definition of the base of the Hettangian, using *Psiloceras planorbis* as defined in the British Isles (see Warrington, 2003; Bloos, 2006), the choice of the CIE would result in putting known psiloceratid ammonoids in the Jurassic and therefore would reduce confusion (or difficulty) in distinguishing amongst poorly preserved psiloceratid species.

As summarized below, the CIE at the Ferguson Hill section is a short-lived event within a continuous sedi-mentary succession that exhibits attributes permitting widespread correlation:

- A CIE is a global, geologically isochronous event;
- The CIE is easily recognizable both by its magnitude and its profile geometry;
- The CIE in the Ferguson Hill section is within a continuous sedimentary succession;
- The CIE at Ferguson Hill can be correlated to numerous sections from low to mid-paleolatitudes in shallow and deep marine environments;
- The CIE can potentially be correlated to other marine and continental sedimentary strata of different facies;
- The CIE at Ferguson Hill is closely associated with biovents including the FODs of *Psiloceras tilmanni* group ammonoids and the bivalve *Agerchlamys boellingi*, which can serve as proxies for recognizing the base Hettangian;
- The CIE at Ferguson Hill and other localities is positioned above the youngest Triassic ammonoid *Choristoceras crickmayi* and below ammonoids of the *Psiloceras tilmanni* group, thus preserving recent temporal concepts for these taxa and their stage/system assignments.

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