

## Discussion - Reply

**Cite this article:** Landing ED, Ripperdan RL, and Geyer G (2022) Discussion of ‘Reply to “Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous”’. *Geological Magazine* **159**: 173–176. <https://doi.org/10.1017/S001675682100090X>

Received: 26 January 2021

Revised: 11 July 2021

Accepted: 5 August 2021

First published online: 2 November 2021

**Keywords:**

Cambrian; carbon isotope excursions; HERB excursion; “TOCE”

**Author for correspondence:**

Ed Landing,

Email: [ed.landing@nyused.gov](mailto:ed.landing@nyused.gov)

# Discussion of ‘Reply to “Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous”’

ED Landing<sup>1,2</sup> , Robert L. Ripperdan<sup>2</sup> and Gerd Geyer<sup>3</sup> 

<sup>1</sup>New York State Museum, 222 Madison Avenue, Albany, NY 12230, USA; <sup>2</sup>Montgomery County Public Schools, Montgomery City, MO 63361, USA and <sup>3</sup>Lehrstuhl für Geodynamik und Geomaterialforschung, Institut für Geographie und Geologie, Bayerische Julius-Maximilians-Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

**Abstract**

No basis for controversy exists in the naming of a global, strongly negative, uppermost Cambrian carbon isotope ( $\delta^{13}\text{C}$ ) excursion. The HERB Event (HERB) has met the standards for chemostratigraphic units (i.e. consistent biostratigraphic brackets, content and concept) since 1992. By comparison, the TOCE excursion morphed through four temporally distinct  $\delta^{13}\text{C}$  events with spike-like nadirs that shifted temporally through the uppermost Cambrian until its synonymization with HERB (2006–12). In 2018, TOCE became a prolonged interval with very early onset and enveloped HERB – meaning five TOCE homonyms have been unambiguously defined and figured. HERB lies in the high-diversity Ptychaspid bioturbation (trilobites) and below the Ptychaspid extinction. But, data on it were used in TOCE’s 2006 proposal and in later iterations (2008, 2012) to show it (1) higher, both at and above the Ptychaspid extinction; (2) at the level of HERB (2012, 2018); and (3) even extending well below HERB (2018). TOCE fails the recommendations for a formal chemostratigraphic unit. Its relationship to latest Cambrian biotic turnover includes equation with extinction and high-diversity intervals. One TOCE homonym is a synonym, albeit junior, of HERB.

**1. Introduction**

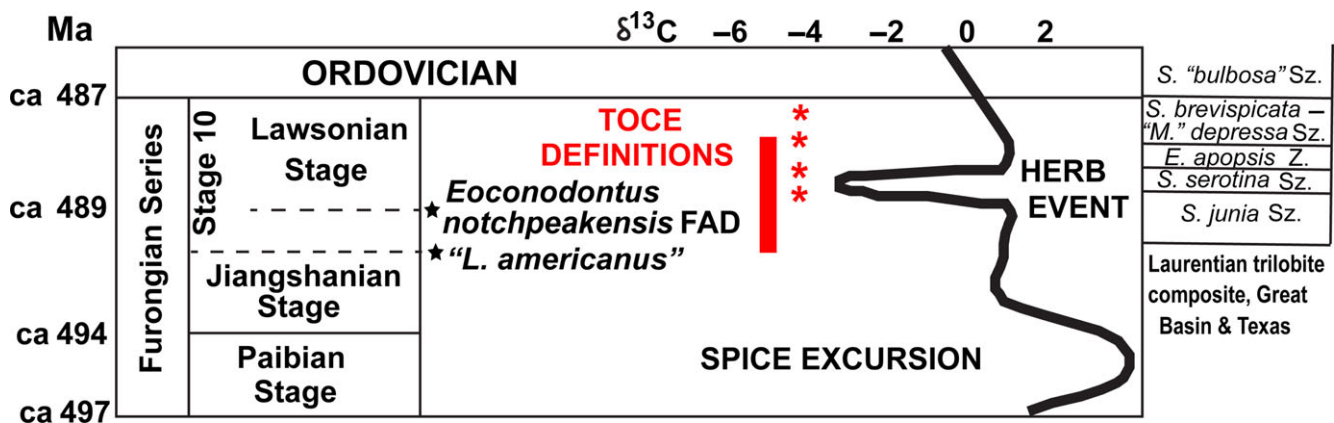
Variations in geochemical properties in sedimentary successions (i.e. rock (including ice), soil) contribute to geologic synthesis and temporal correlation. Chemostratigraphic excursions or events are physical stratigraphic units that reflect environmental changes, and require a formal methodology and standardized terminology just like litho- and biostratigraphic units in the North American and international stratigraphic codes (e.g. Ramkumar, 2015). (The following acronyms are used below: HERB, Hellnmaria–Red Tops Boundary (Miller *et al.* 2006), and TOCE, Top of Cambrian Excursion (Zhu *et al.*, 2006).)

Chemostratigraphic units require documentation of geochemical changes through a litho-sequence, consistent ranges shown by independent markers (bio-, magnetostratigraphic, etc.) and reference sections (Scott *et al.* 2020). Use of a chronostratigraphic unit must be consistent with its original concept and not replace a pre-existing unit as a synonym (Scott *et al.* 2020). These considerations emphasize HERB’s utility as an Upper Cambrian correlation tool. (In this report, the Cambrian is divided into three subsystems and subperiods (Lower/Early, Middle/Middle, Upper/Late); the undefined divisions ‘lower/early’, ‘middle/middle’ and ‘upper/late’ are not used; Landing *et al.* 2020b).

**2. Multiple TOCE homonyms**

Discussion of the HERB and TOCE events allows application of Scott *et al.*’s (2020) recommendations for defining chemostratigraphic units. It also emphasizes the problem with the creation of multiple homonyms of chemostratigraphic events in geological correlation.

TOCE of Zhu *et al.* (2006) was based on Buggisch *et al.*’s (2003) synthesis, not their field and laboratory work. Buggisch *et al.* (2003) reported  $\delta^{13}\text{C}$  results from Argentina. They identified a strong uppermost Cambrian negative  $\delta^{13}\text{C}$  excursion known in Laurentia (Utah) and Australia (Ripperdan *et al.* 1992; Ripperdan & Miller, 1995; Dattilo *et al.* 2004; Fig. 1) in the unfossiliferous lower La Silla Formation. The Utah and Australian areas show a strong negative excursion in the Upper Cambrian *Saukiella junia* Subzone (trilobites) and equivalents, and its onset above the *Eoconodontus* Zone base (conodonts). It is not accurate to say that TOCE was ‘not tied precisely to the trilobite and conodont zonation available at the time’ (Zhu *et al.* 2020). Indeed, TOCE was



**Figure 1.** (Colour online) HERB Event with multiple TOCE nadirs at asterisks in *E. apopsis* Subzone (Zhu et al. 2006, fig. 6); “*M.*” *depressa* Subzone – *S. brevispicata* Zone (Peng & Babcock, 2008); *Saukiella serotina* and *S. junia* subzones (Peng et al. 2012; Terfelt et al. 2014). Vertical bar is TOCE band (Zhu et al. 2018) with anomalously early onset (cf. onset in *S. junia* Subzone in Peng et al. 2012) and top of TOCE not defined in Zhu et al. (2018). After Landing et al. (2011, figs 1, 4). Abbreviations: *E.*, *Eureka*; “*M.*”, *Missisquoia*; *P.*, *Prosaugia*; *Sz.*, Subzone; *Z.*, Zone. Informal Stage 10 base at lowest occurrence of problematical ‘*Lotagnostus americanus*’ (i.e. Landing et al. 2011).

clearly described as identical to the uppermost Cambrian negative excursion in Laurentia, Australia and Argentina using Buggisch et al. (2003). However, it was figured at a much higher interval than the *S. junia* Subzone and tied to the ‘Mass Extinction (Ptychaspid Biome)’ horizon (Zhu et al. 2006, fig. 1, their quotation marks).

Portrayal of TOCE as a negative  $\delta^{13}\text{C}$  spike above the *Saukiella junia* Subzone was not correct (see strong excursion and nadir in the *S. junia* Subzone in Ripperdan et al. 1992; Ripperdan & Miller, 1995; Dattilo et al. 2004; Miller et al. 2006). This placement may follow a belief that carbon isotope excursions ‘seem to coincide with important biotic events’ (Zhu et al. 2006), but Laurentia and Australia show the event in a high-diversity, not extinction, interval (e.g. Taylor, 2006).

The reason for the upward migration of TOCE and its nadir higher into the Laurentian *Missisquoia depressa* Subzone – *Symphysurina brevispicata* Zone (Peng & Babcock, 2008, fig. 4.4; Fig. 1) was unexplained. This interval does not have a strong negative  $\delta^{13}\text{C}$  excursion (e.g. Ripperdan & Miller, 1995; Fig. 1), although it actually corresponds to an ‘important biotic event’ thesis in Zhu et al. (2006; see ptychaspid biome review in Landing et al. 2020a). The 2006 and 2008 reports established biostratigraphically distinct TOCE homonyms 1 and 2.

TOCE was later ‘dropped down’ into the ptychaspid biome with a sharp nadir in the *Saukiella serotina* Subzone (Peng et al. 2012, p. 440, fig. 19.3; i.e. homonym 3). The latter report said this event was ‘previously referred to as the HERB Event’, with Ripperdan et al. (1992) given as the source. This purported reference is 10 years before ‘HERB Event’ was first used (Ripperdan, 2002; Dattilo et al. 2004). In addition, there is no Ripperdan et al. (1992) report, and the HERB Event always was in the older *S. junia* Subzone (e.g. Ripperdan et al. 1992). In the same report, Peng et al. (2012, p. 454) created homonym 4 by putting the TOCE onset at the ‘base of the *E. notchpeakensis* Subzone ... equivalent to the ... *Saukiella junia* Subzone ...’

Zhu et al. (2018, figs 2, 4) do not record TOCE in  $\delta^{13}\text{C}$  data from South China. They show a protracted ‘global’ TOCE (homonym 5) that extends very low to the base of informal Cambrian Stage 10 as

they define it (i.e. Zhu et al. 2006). This is below the *Saukiella junia* Subzone and equivalents (Fig. 1). TOCE homonym 5 extends into middle Stage 10 with a major negative  $\delta^{13}\text{C}$  excursion cap, likely the traditional HERB Event. Homonym 5 excludes the higher TOCE homonym 2 of Peng & Babcock (2008). Two strong negative  $\delta^{13}\text{C}$  nadirs low in the TOCE band (Zhu et al. 2018) are unknown in coeval carbon isotope excursions, and their basis is unknown to us. The 2018 TOCE brackets a prolonged ‘Mass Extinction (Ptychaspid Biome)’ (Zhu et al. 2018, their quotation marks). This relationship of biotic change to chemostratigraphic events follows Zhu et al. (2006; Zhu et al. 2020, p. 3) in that ‘the timing of the extinction is clearly linked to the TOCE’, but it must be noted that TOCE homonym 5 is below the *Eureka apopsis* Zone extinction and in a high-diversity interval (Taylor, 2006; Landing et al. 2020a).

### 3. Utility of HERB event

Since a strong negative Upper Cambrian  $\delta^{13}\text{C}$  event was first reported (Ripperdan et al. 1992) and termed an ‘excursion’ (Ripperdan & Miller, 1995; Miller et al. 2011) or ‘event’ (Ripperdan, 2002; Dattilo et al. 2004), it has been recorded globally in the *Saukiella junia* Subzone or equivalents. It should be noted that no consistent distinction exists between chemostratigraphic ‘events’ and ‘excursions’, with many ‘events’ (e.g. GICE, OAB 1–3) having long durations (Scott et al. 2020).

Rather than being tightly and consistently bracketed, TOCE has ranged through seven trilobite subzones and zones (Landing et al. 2020a; Fig. 1). Zhu et al. (2020, pp. 1, 2) claim ‘subsequent attempts to tie [TOCE] into an evolving biostratigraphic and geochronologic framework have seemingly led to the erroneous statement that the TOCE “has had its biostratigraphic and geochronologic position changed in successive publications”’; but the syntheses by Zhu and colleagues since 2006 void this argument (Landing et al. 2020a; Fig. 1). An ‘evolving biostratigraphic and geochronologic framework’ leading to disparate TOCE definitions (Zhu et al. 2020) does not explain its changing position: the Queensland and Utah biostratigraphies are virtually unchanged since the first work on their  $\delta^{13}\text{C}$  profiles (Ripperdan et al. 1992).

A forced synonymy of names, not biostratigraphically bracketed chemostratigraphic units, led to TOCE's later representation as a sharp nadir in the *Saukiella junia* Subzone and equivalents (Terfelt *et al.* 2014; Ahlberg *et al.* 2019; homonym 4) or a broad uppermost Cambrian band (Zhu *et al.* 2018; TOCE homonym 5) that envelops the earlier-documented, biostratigraphically unvarying HERB (Ripperdan *et al.* 1992; Ripperdan & Miller, 1995; Miller *et al.* 2006). Thus, only TOCE homonym 4 is a synonym (albeit junior) of HERB.

Zhu *et al.* (2020) argue that HERB is not legitimate as the acronym was not explained when proposed, although named chemostratigraphic events, if acronyms, are often not explained (Scott *et al.* 2020). Zhu *et al.* (2020) thus assert a well-defined acronym has priority over the detailed biostratigraphy of the HERB Event in the same volume where TOCE was proposed based on data from the literature (Miller *et al.* 2006, p. 400, fig. 12; Zhu *et al.* 2006). In Zhu *et al.* (2006), TOCE's brackets are ambiguous, unrelated to a stratigraphic section, and its lower part is referable to three possible 'Ptychaspid Biomere Extinction Interval' horizons (Landing *et al.* 2020a).

Zhu *et al.* (2020) noted HERB was not named in a formal publication (i.e. Ripperdan, 2002) as required by the North American Commission on Stratigraphic Nomenclature (2005), although no recommendations existed for chemostratigraphic unit names until recently (Scott *et al.* 2020). TOCE's changing biostratigraphic position is shown in reports since 2006 (Fig. 1), but HERB's bracketing and correlation across Laurentia, Baltica, Gondwana (Australia, Argentina), North China (Dayancha) and Kazakhstan are unchanged for almost 30 years (Landing *et al.* 2020a).

#### 4. Discussion

Chemostratigraphic units require consistent definition (i.e. Ramkumar, 2015). Zhu *et al.* (2020, p. 1) claim TOCE is 'a well-documented and clearly defined  $\delta^{13}\text{C}_{\text{carb}}$  excursion, and that the term "HERB Event" was originally used informally, without definition or reference data, for a negative  $\delta^{13}\text{C}_{\text{carb}}$  peak, a peak later shown to occur within the TOCE excursion'. This ignores the changing TOCE concepts since 2006 – variously a sharp negative event younger than or equated with and finally expanded to envelop HERB, and figured through seven Laurentian biostratigraphic intervals (zones and subzones). That 'the stratigraphic position of the TOCE has shifted through four biotic intervals is simply incorrect' (Zhu *et al.* 2020) is itself incorrect is shown by historical review (Landing *et al.* 2020a; Fig. 1). Zhu *et al.* (2020) claimed Landing *et al.* (2020a) were 'misleading and replete with misconceptions' and 'misunderstood' the relationship of HERB to TOCE – although Landing *et al.*'s discussion follows recommendations consistent with determining priority in stratigraphic nomenclature (i.e. North American Commission on Stratigraphic Nomenclature, 2005; Scott *et al.* 2020; Fig. 1). Landing *et al.* (2010, 2011) proposed the end-Cambrian Lawsonian Stage with a base at the lowest *Eoconodontus notchpeakensis* just below the HERB onset (Fig. 1). This proposal makes the unchanging definition and correlation of HERB particularly important.

**Acknowledgements.** The constructive comments of the reviewers are appreciated.

#### References

- Ahlberg P, Lundberg F, Erlström M, Calner M, Lindskog A, Dahlqvist P and Joachimski MM (2019) Integrated Cambrian biostratigraphy and carbon isotope chemostratigraphy of the Grönhögen-2015 drill core, Öland, Sweden. *Geological Magazine* 156, 935–49.
- Buggisch W, Keller M and Lehnert O (2003) Carbon isotope record of Late Cambrian to Early Ordovician carbonates of the Argentine Precordillera. *Palaeogeography, Palaeoclimatology, Palaeoecology* 195, 357–73.
- Dattilo BF, Hlohowsky JS, Ripperdan RL, Miller JF and Shapiro R (2004) Stratigraphic setting of an Upper Cambrian metazoan reef between the Nopah Formation to Goodwin Formation Transition in southern Nevada. *Geological Society of America, Abstracts with Programs* 36, 368.
- Landing E, Geyer G., Schmitz MD, Wotte T and Kouchinsky A (2020b) (Re) proposal of three Cambrian subsystems and their geochronology. *Episodes* 36, 280–8.
- Landing E, Ripperdan RL and Geyer G (2020a) Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous. *Geological Magazine* 157, 1373–7.
- Landing E, Westrop SR and Adrain JM (2011) The Lawsonian Stage: the *Eoconodontus notchpeakensis* (Miller, 1969) FAD and HERB carbon isotope excursion define a globally correlatable terminal Cambrian stage. *Bulletin of Geosciences* 86, 621–40.
- Landing E, Westrop SR and Miller JF (2010) Globally practical base for the uppermost Cambrian (Stage 10): FAD of the conodont *Eoconodontus notchpeakensis* and the Housian [*sic*, 'Lawsonian' as in abstract] Stage. In *15th Field Conference of the Cambrian Stage Subdivision Working Group. Abstracts and Excursion Guide* (eds O Fatka and P Budil), p. 18. Prague: Czech Geological Survey.
- Miller JF, Ethington RL, Evans KR, Holmer LE, Loch JD, Popov LE, Repetski JE, Ripperdan RL and Taylor JF (2006) Proposed stratotype for the base of the highest Cambrian stage at the first appearance datum of *Cordylodus andresi*, Lawson Cove section, Utah, USA. *Palaeoworld* 15, 384–405.
- Miller JF, Evans KR, Freeman R, Ripperdan R and Taylor JF (2011) Global stratotype of the Lawsonian Stage. *Bulletin of Geosciences, Czech Geological Survey* 86, 595–620.
- North American Committee on Stratigraphic Nomenclature (2005) North American Stratigraphic Code. *AAPG Bulletin* 89, 1547–91.
- Peng SC, Babcock LE and Cooper RA (2012) The Cambrian period. In *The Geologic Time Scale 2012* (eds FM Gradstein, JG Ogg, M Schmitz and G Ogg), pp. 437–88. Amsterdam: Elsevier.
- Peng SC and Babcock LE (2008) Cambrian period. In *The Concise Geologic Time Scale* (eds J Ogg, G Ogg and FM Gradstein), pp. 37–46. Cambridge: Cambridge University Press.
- Ramkumar M (2015) Toward standardization of terminologies and recognition of chemostratigraphy as a formal stratigraphic method. In *Chemostratigraphy: Concepts, Techniques, and Applications* (ed. M Ramkumar), pp. 1–21. Amsterdam: Elsevier.
- Ripperdan RL (2002) The HERB Event: end of Cambrian carbon cycle paradigm? *Geological Society of America, Abstracts with Programs* 34, 413.
- Ripperdan RL, Magaritz M, Nicoll RS and Shergold JS (1992) Simultaneous changes in carbon isotopes, sea level, and conodont biozones within Cambrian–Ordovician boundary interval at Black Mountain, Australia. *Geology* 20, 1039–42.
- Ripperdan RL and Miller JF (1995) Carbon isotope ratios from the Cambrian–Ordovician boundary section at Lawson Cove, Wah Wah Mountains, Utah. In *Ordovician Odyssey: Short Papers for the Seventh International Symposium on the Ordovician System* (ed. JD Cooper), pp. 129–32. Fullerton, CA: SEPM, Pacific Section, 77.
- Scott RW, Brett CE, Flugeman RH and Pratt BR (2020) North American Commission on Stratigraphic Nomenclature. Note 71 – Application for addition of chemostratigraphic units to the North American Stratigraphic Code: a case for formalizing chemostratigraphic units. *Stratigraphy* 17, 135–9.
- Taylor JF (2006) History and status of the biomere concept. *Memoirs of the Association of Australasian Palaeontologists* 32, 247–65.

- Terfelt F, Eriksson ME and Schmitz B** (2014) The Cambrian–Ordovician transition in dysoxic facies in Baltica: diverse faunas and carbon isotope anomalies. *Palaeogeography, Palaeoclimatology, Palaeoecology* **394**, 59–73.
- Zhu MY, Babcock LE and Peng SC** (2006) Advances in Cambrian stratigraphy and paleontology: integrating correlation techniques, paleobiology, taphonomy and paleoenvironmental reconstruction. *Palaeoworld* **15**, 217–22.
- Zhu MY, Babcock LE, Peng SC and Ahlberg P** (2020) Reply to ‘Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous’. *Geological Magazine* 157. doi: [10.1017/S0016756820001120](https://doi.org/10.1017/S0016756820001120).
- Zhu MY, Yang AH, Yuan JL, Li GX, Zhang JM, Zhao FC, Ahn SY and Miao LY** (2018) Cambrian integrative stratigraphy and timescale of China. *Science China Earth Sciences* 61. doi: [10.1007/s11430-017-9291-0](https://doi.org/10.1007/s11430-017-9291-0).