Geological Magazine

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Cite this article: Zhu M, Babcock LE, Peng S, and Ahlberg P (2021) Reply to 'Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous'. *Geological Magazine* **158**: 1323–1326. https://doi.org/10.1017/S0016756820001120

Received: 26 July 2020
Accepted: 15 September 2020
First published online: 12 October 2020

Keywords:
Cambrian; Chemostratigraphy; TOCE; HERB

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Reply to 'Uppermost Cambrian carbon chemostratigraphy: the HERB and undocumented TOCE events are not synonymous'

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Abstract

In a recent communication on carbon isotope chemostratigraphy of the uppermost Cambrian strata, it was claimed that the Top of Cambrian Excursion (TOCE) is (1) an undocumented negative $\delta^{13}C_{carb}$ excursion; (2) ambiguously defined; (3) deliberately fictitious or, in the authors' words, a 'nihilartikel'; and (4) not synonymous with the Hellnmaria–Red Tops Boundary (HERB) Event. As the authors who have been involved in much of the discussion surrounding the TOCE since its introduction and in subsequent clarification, we wish to emphasize that the recent communication overlooks the fact that the TOCE is in fact a well-documented and clearly defined negative $\delta^{13}C_{carb}$ excursion, and that the term 'HERB Event' was originally used informally, without definition or reference data, for a negative $\delta^{13}C_{carb}$ peak, a peak later shown to occur within the TOCE excursion. Nearly a decade after the TOCE was named, the concept of the HERB Event was modified from a negative $\delta^{13}C_{carb}$ peak to a negative $\delta^{13}C_{carb}$ excursion, making it conceptually synonymous with the TOCE excursion. The recently published commentary is misleading and replete with misconceptions, as we discuss here.

1. The TOCE is a well-documented, negative $\delta^{13}C_{carb}$ excursion with explicit definition

The assertion by Landing *et al.* (2020) that the Top of Cambrian Excursion (TOCE) was named 'without stratigraphic or laboratory data or reference to previous studies or a representative section, and these data have never been provided' is demonstrably incorrect. The TOCE was originally defined (Zhu *et al.* 2006, p. 220) as 'a large negative excursion close to the end of the Cambrian System (uppermost part of Stage 10 and the Furongian Series)' in a synthetic paper that presented the first composite Cambrian $\delta^{13}C_{carb}$ chemostratigraphic profile (Zhu *et al.* 2006). As Zhu *et al.* (2006) explained in the caption to their figure 1 and in the reference list, the composite Cambrian carbon isotope excursion was based on various published $\delta^{13}C_{carb}$ datasets. Specifically, the TOCE was based on the suggestion of Buggisch *et al.* (2003, fig. 8) that prominent $\delta^{13}C_{carb}$ negative excursions identified from the *Eoconodontus* Conodont Zone of the Argentine Precordillera, the Black Mountain section of Australia (Ripperdan *et al.* 1992), and the Lawson Cove section of Utah, USA (Ripperdan & Miller, 1995) were synchronous and could be used for global correlation of Cambrian–Ordovician boundary sections worldwide. As that level is close to the Cambrian–Ordovician boundary, it was designated as the TOCE.

The TOCE was not tied to biozonation when named (Zhu *et al.* 2006), and not tied precisely to the trilobite and conodont zonation available at the time (summarized in Peng & Babcock, 2008). Also, robust geochronologic constraints were not available for biozones in the uppermost Cambrian strata at that time. Although the definition of the TOCE has not changed since its original publication, subsequent attempts to tie its position 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' (Landing *et al.* 2020). To minimize ambiguity in its recognition, Peng *et al.* (2012) identified the TOCE as a negative $\delta^{13}C_{carb}$ excursion within the *Eoconodontus* Conodont Zone. Its onset was regarded as occurring about halfway through provisional Stage 10, with the return to positive values being a little below the Ordovician base (Peng *et al.* 2012, p. 454–5). Further means of recognition were provided in a correlation chart showing the stratigraphic position of the TOCE in relation to the trilobite zonation in South China, Siberia, Australia and Laurentia (Peng *et al.* 2012, fig. 19.3).

https://doi.org/10.1017/S0016756820001120 Published online by Cambridge University Press

Since its introduction in 2006, the TOCE has been a widely used chemostratigraphic term among the Cambrian community. The term has been adopted and discussed by numerous authors, including Landing and colleagues (e.g. Terfelt *et al.* 2014; Li *et al.* 2017; Westrop & Landing, 2017; Ahlberg *et al.* 2019; Geyer, 2019; Scorrer *et al.* 2019; Zhu *et al.* 2019), and it has been adopted for use in the Geologic Time Scale volumes (Ogg *et al.* 2008, 2016; Gradstein *et al.* 2012, in press).

2. The HERB Event is synonymous with the TOCE

The term HERB (later defined as Hellnmaria–Red Tops Boundary) first appeared in a Geological Society of America (GSA) meeting abstract as a Sunwaptan-aged $\delta^{13}C$ event recognized in Australia, Newfoundland and western North America, but it appeared without reference data and explanation of the acronym (Ripperdan, 2002). Its first appearance in a formal publication, again without explanation of the acronym, was in a paper by Miller *et al.* (2006, p. 400) who defined the HERB Event as a 'distinctive negative peak at point B' in the Lawson Cove section of Utah (Miller *et al.* 2006, fig. 12). The peak occurs within a broader negative $\delta^{13}C_{carb}$ excursion. Miller *et al.* (2006, fig. 12) correlated the HERB Event to an equivalent negative $\delta^{13}C_{carb}$ peak in the Black Mountain, Australia, section. The $\delta^{13}C_{carb}$ dataset used to define the HERB Event was published earlier by Ripperdan *et al.* (1992) and Ripperdan & Miller (1995). The dataset is the same as that cited by Buggisch *et al.* (2003) and subsequently used for defining the TOCE. Under the definition of Miller *et al.* (2006), the HERB Event represents a nadir within the TOCE excursion.

The acronym HERB was defined by Miller *et al.* (2014, 2015), 12 years after the term was first used by Ripperdan (2002). The Hellnmaria and Red Tops members belong to the Notch Peak Formation. In their 2015 paper, Miller *et al.* (2015) modified the concept of the HERB Event, redefining it as 'a prominent excursion that begins slightly above the boundary between the Hellnmaria and Red Tops Members and continues into the Lava Dam Member' in Utah. Under the modified definition, the HERB was expanded across a rather lengthy stratigraphic interval. Although predominantly a negative excursion ($\delta^{13}C_{carb}$) interval, the new definition encompasses an interval having large $\delta^{13}C_{carb}$ variability, including stratigraphic levels with distinctly positive values, in four Utah sections (Miller *et al.* 2015, fig. 8). The most consistently negative part of the redefined excursion is nearly restricted to an interval within the Red Tops Member.

Miller *et al.* (2015) described the HERB as a prolonged episode, characterized predominantly by a negative $\delta^{13}C_{carb}$ profile. As such, it is a better match conceptually to the definition of the TOCE. Largely for this reason, the HERB Event has commonly been referred to as synonymous with the TOCE in Cambrian stratigraphy (Peng *et al.* 2012, in press; Terfelt *et al.* 2014; Li *et al.* 2017; Ahlberg *et al.* 2019; Harper *et al.* 2019; Geyer, 2019; Scorrer *et al.* 2019; Zhu *et al.* 2019).

Landing *et al.* (2011) added confusion to discussions of uppermost Cambrian stratigraphy by erroneously recognizing the HERB Event and the TOCE as two separate phenomena within Stage 10 (Landing *et al.* 2011, fig. 1). According to their illustration, the HERB Event preceded the onset of the TOCE. We never intended to recognize the HERB and TOCE as separate, successive excursions, and we know of no dataset supporting the isotopic profile for the uppermost Cambrian strata presented by Landing *et al.* (2011, fig. 1). In their recent communication, Landing *et al.* (2020) stated that they now consider the 'credulously accepted existence' of the TOCE as an excursion above the HERB (Landing *et al.* 2011) to be a 'nihilartikel'. In their view, the TOCE excursion is not synonymous with the HERB Event because of its 'ever-shifting meaning' (Landing *et al.* 2020, fig. 1). This misunderstanding by Landing and colleagues seems to owe its origin to a combination of factors, as follows.

(1) Failure to recognize that the TOCE was adequately defined, and was supported by published data (Buggisch *et al.* 2003), as explained above.
(2) Controversy over the level of the base of provisional Stage 10, which is pending ratification. The International Subcommission on Cambrian Stratigraphy voted to accept the first appearance datum (FAD) of the agnostoid *Lotagnostus americanus* as the marker for the base of Stage 10 (Babcock *et al.* 2005; see also Peng & Babcock, 2005, 2008; Peng *et al.* 2012). Landing and others (Landing *et al.* 2011; Miller *et al.* 2015) subsequently indicated support for a much higher level, identified by the FAD of a conodont, *Eoconodontus notchpeakensis*. In proposing an alternative level for the base of the stage, and simultaneously introducing the idea that the TOCE and HERB represent successive, unrelated chronostratigraphic markers, Landing *et al.* (2011) squeezed the TOCE excursion into a narrowed stratigraphic interval, erroneously placing it closer to the ratified base of the Ordovician System. Recognizing the HERB as an earlier event, an event whose stratigraphic record is close to the level of *E. notchpeakensis*, Landing *et al.* (2011) significantly compounded the error, with the result being further misunderstanding of the criteria under consideration for defining the base of the stage.
(3) A suggested link between the TOCE and the mass extinction associated with the Ptychaspid Biomere illustrated by Zhu *et al.* (2006, fig. 1). In their recent communication, Landing *et al.* (2020) stated that the TOCE 'seems to be correlated into the *Eurekia apopsis* Zone (trilobites) of Laurentia' because the Ptychaspid Biomere extinction has had a number of different definitions (Taylor, 2006). It is true that differing biostratigraphic levels have been proposed for the top of the Ptychaspid Biomere. Despite differences in interpretation about the position of the biomere top, the timing of extinction is clearly linked to the TOCE excursion. The extinction level was recently placed at the base of the *Cordylodus proavus* Zone, that is, near the top of the TOCE by Miller *et al.* (2018). It should be emphasized that the TOCE excursion was shown to be within the *Eoconodontus* Conodont Zone, equivalent to the middle of the *Saukia* Zone (*Saukiella junia* Polymerid Trilobite Subzone) in Laurentia (Peng *et al.* 2012, p. 454). The argument that the inferred stratigraphic position of the TOCE has shifted through four biotic zones (Landing *et al.* 2020) is simply incorrect.

To summarize, the interpretation that the HERB Event and the TOCE excursion are separate $\delta^{13}C_{carb}$ entities (Landing *et al.* 2011, 2020) is a misunderstanding, as discussed elsewhere (e.g. Peng *et al.* 2012, in press; Terfelt *et al.* 2014; Miller *et al.* 2015; Li *et al.* 2017; Ahlberg *et al.* 2019; Geyer, 2019; Harper *et al.* 2019; Scorrer *et al.* 2019; Zhu *et al.* 2019), and as elaborated here. Geyer (2019), in particular, noted that the HERB and TOCE represent the 'same fluctuation in ocean chemistry' and that 'no negative $\delta^{13}C$ excursion is recorded above the HERB peak in North America' (Geyer, 2019).

3. The HERB Event is an invalid synonym of the TOCE

Landing *et al.* (2020) commented that there is no formal procedure for the proposal, naming, description and definition of chemostratigraphic units in the International Stratigraphic

https://doi.org/10.1017/S0016756820001120 Published online by Cambridge University Press

Code. They claimed that 'At the Geological Society of America 2019 meeting in Phoenix, the NACSN (North American Commission on Stratigraphic Nomenclature) confirmed its commitment to developing consistent stratigraphic and nomenclatural principles and practices for formal chemostratigraphic units' (no formal document is provided). However, the NACSN is undoubtedly aware that any guidelines for global stratigraphic nomenclature must be formulated and approved by the International Commission on Stratigraphy. The current Code makes clear that, for priority considerations to take effect, any formally established stratigraphic unit-term must be published in a suitable scientific medium. The Code states specifically that 'Abstracts, most fieldtrip guidebooks, dissertations, company reports, open file reports and similar media generally do not meet this requirement' (see Murphy & Salvador, 1999). By way of comparison, Landing *et al.* (2020) also commented that 'it is impossible that a formal taxon name would be accepted without diagnosis or reference to existing work, or later used to supplant an existing name despite knowledge of the original taxon. Such a proposal would not be sanctioned under existing International Commission on Zoological Nomenclature and/or International Code of Botanical Nomenclature rules and regulations.' This statement is misleading, however, as any new taxon mentioned in an informal medium such as an abstract would not be considered available (validly described) according to the International Code of Zoological Nomenclature (1999).

The name 'Top of Cambrian Excursion', with the acronym TOCE, was defined and published, with reference to supporting isotopic data (Buggisch *et al.* 2003), as a negative $\delta^{13}C$ excursion near the top of the Cambrian System in a refereed journal article (Zhu *et al.* 2006, p. 220). In contrast, the acronym HERB first appeared in a GSA meeting abstract (Ripperdan, 2002) with neither definition nor referenced data. As this mention does not meet the most basic requirement for publication of a formal stratigraphic term, its usage in this sense should be considered informal. The term 'HERB Event' was first used in a formal journal article which appeared (Miller *et al.* 2006, p. 400) later in the same volume that the TOCE was named (Zhu *et al.* 2006, p. 220). Where it first appeared (Miller *et al.* 2006, p. 400), it was defined as a negative isotopic peak at a specific point in section, but there was no explanation of the meaning of the acronym. That point was shown (Miller *et al.* 2006, fig. 12) to lie within the negative isotopic excursion defined earlier in the volume (Zhu *et al.* 2006, p. 220) as the TOCE. The HERB is unequivocally a synonym, and arguably a junior synonym by reason of priority, of the TOCE. For this reason, TOCE, not HERB, was adopted for use in the Geologic Time Scale volumes (Ogg *et al.* 2008, 2016; Gradstein *et al.* 2012, in press).

As a final note, Sial *et al.* (2008, p. 438) recognized a $\delta^{13}C_{carb}$ excursion in the uppermost Cambrian strata of the Argentine Precordillera, which they named 'SNICE' (Sunwaptan negative C-isotope excursion). This name of this excursion, which is apparently the same as the TOCE, was introduced without knowledge of earlier names. As a junior synonym, the SNICE has not received broad recognition.

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