Carbon and Sulphur Isotopes from the Cambrian Series 2–Series 3 Boundary: Potential Proxies for Global Correlation?

Thomas Wotte

Abstract The Cambrian Series 2–Series 3 boundary intervals of five mixed carbonate–siliciclastic successions of Gondwana, Laurentia, and Siberia were analysed for their carbonate carbon isotopes ($\delta^{13}C_{carb}$) and sulphur isotopes from carbonate-associated sulphate ($\delta^{34}S_{CAS}$). For all sections, the boundary interval is characterized by distinct positive $\delta^{13}C_{carb}$ excursions, flanking the first appearance datum (FAD) of trilobite species applied for the definition of (regional) bases of Cambrian Series 3. Whether the positive $\delta^{13}C_{carb}$ shifts could be used as an additional proxy for an intercontinental correlation of the base of Cambrian Series 3 needs to be evaluated. No distinct positive and/or negative $\delta^{34}S_{CAS}$ excursions are discernible for the investigated successions. However, $\delta^{34}S_{CAS}$ data provide important information for the characterization of palaeoenvironmental conditions, but probably give no additional detail for a global correlation of the Cambrian Series 2–Series 3 boundary interval.

Keywords Cambrian series 2–series 3 boundary · Correlation · Sulphur · Carbon

The boundary between the until-recently undefined Cambrian Series 2 and Series 3, traditionally known as the lower–middle Cambrian boundary, is one of the most controversial time intervals in respect of the biostratigraphic subdivision of the Phanerozoic. Whereas the base of the Cambrian (Terreneuvian Series: Fortunian Stage), the boundary between Cambrian Series 3 and the Furongian, and the Furongian–Ordovician boundary have all been internationally defined by the IUGS, no agreement yet exists with regard to defining the boundary between Cambrian Series 2 and Cambrian Series 3 (Fig. 1). Because of the distinct provincialism of biostratigraphically relevant taxa (archaeocyaths and trilobites), it is not possible to correlate regional stratigraphic schemes on an intercontinental scale, and even on a regional scale, correlation is difficult at present.

T. Wotte (✉)
Institut für Geologie und Mineralogie, Universität zu Köln, Zülpicher
Straße 49a, 50674 Köln, Germany
e-mail: thomas.wotte@uni-koeln.de

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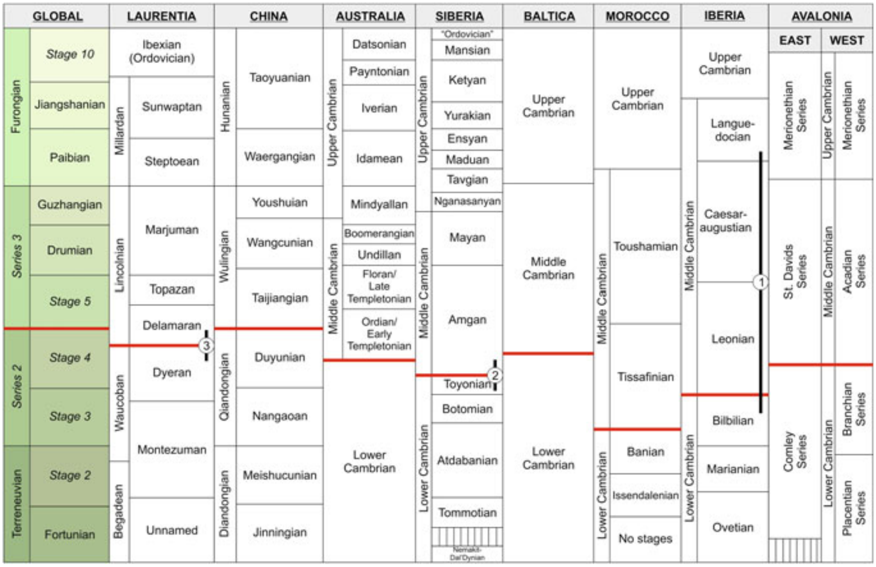

Fig. 1 Chart showing correlation schemes for the Cambrian as used in various regions of the world compared to global chronostratigraphic usage (modified from Babcock and Peng 2007 and Geyer and Landing 2004). *Red lines* mark the position of the traditional *lower–middle* Cambrian boundary. Stratigraphic ranges of (*1*) the analysed sections of West Gondwana, (*2*) the Molodo River section, and (*3*) the Split Mountain section are marked

Recently, two levels for the definition of a GSSP for the base of Cambrian Series 3 have been discussed. The first candidate is the FAD of *Oryctocephalus indicus*, and the second is the FAD of *Ovatoryctocara granulata* (cf. Peng and Babcock 2011; Sundberg et al. 2011). Candidate sections under consideration are the Wuliu–Zengjiayan section (Guizhou, southern China), the Molodo River section (Yakutia, Siberia), and the Split Mountain section (Nevada, USA). According to Geyer and Peel (2011), the FAD level of *Oryctocephalus indicus* as localized in southern China and Laurentia cannot be verified precisely in other Cambrian palaeogeographical regions such as West Gondwana, Baltica, or Avalonia, and is thus not applicable under the definition of a GSSP. In contrast, *Ovatoryctocara granulata* can be recognized on a broader geographic scale, supporting its potential for intercontinental correlation. However, even if the majority of stratigraphic information for the selection of a GSSP for the Cambrian Series 2–Series 3 boundary came from biostratigraphic data (Geyer 2001), further nonconventional methods would be necessary to contribute to the efforts of the International Subcommission on Cambrian Stratigraphy in subdividing the Cambrian System into four series. Detailed chemostratigraphic investigation ($\delta^{13}C$, $\delta^{34}S$, $^{87}Sr/^{86}Sr$), combined with litho-, eco-, and magnetostratigraphic data, provides a suitable approach for the definition and correlation of the Cambrian Series 2–Series 3 boundary.

Isotope investigations of high stratigraphic resolution supported by well-established biostratigraphic data are rare. Therefore, mixed carbonate–siliciclastic successions of West Gondwana, Laurentia, and Siberia were investigated for their carbonate carbon isotopes ($\delta^{13}C_{carb}$) and sulphur isotopes from carbonate-associated sulphate ($\delta^{34}S_{CAS}$) to evaluate their potential and weaknesses for correlation. Sections from West Gondwana were represented by two localities from northern Spain (Crémenes and Genestosa; Cantabrian zone) and one exposure from southern France (Ferrals-les-Montagnes; Montagne Noire) (Wotte et al. 2007; 2012). According to the Iberian nomenclature, the three sections cover the Bilbilian–Languedocian interval (Fig. 1). The traditional lower–middle Cambrian boundary is characterized by the FAD of *Paradoxides (Acadoparadoxides) mureroensis* (Liñán et al. 1993; Geyer and Landing 2004). $\delta^{13}C_{carb}$ values vary between 0.1 ‰ and 2.0 ‰ at Genestosa, between −1.9 ‰ and 1.4 ‰ at Crémenes, and between −3.2 ‰ and 1.6 ‰ at Ferrals-les-Montagnes. For all sections, $\delta^{13}C_{carb}$ data show a general trend towards more positive values up-section. Five distinct positive shifts in the $\delta^{13}C_{carb}$ record can be correlated on regional scale (Wotte et al. 2007). $\delta^{34}S_{CAS}$ values vary between 21.3 ‰ and 32.2 ‰ at Genestosa and between 17.6 ‰ and 30.3 ‰ at Crémenes. Higher variation is detected for the French section (13.1 ‰–33.2 ‰). However, $\delta^{34}S_{CAS}$ data show no correlation with positive or negative excursions (Wotte et al. 2012).

One further carbonate succession, the Molodo River section (Siberian Platform), was investigated (Fig. 1). Molodo River is considered as a potential candidate for defining the GSSP of the base of Cambrian Series 3, marked by the FAD of *Ovatoryctocara granulata* (Shabanov et al. 2008). $\delta^{13}C_{carb}$ values covering the boundary interval are clearly depleted in ^{13}C, ranging from −6.6 ‰ to −2.4 ‰. Two positive $\delta^{13}C_{carb}$ excursions slightly below (−2.8 ‰) and above (−2.4 ‰) the FAD of *Ovatoryctocara granulata* can be verified (Wotte et al. 2011).

Further isotope data were generated from the Laurentian mixed carbonate–siliciclastic Split Mountain section (Nevada), another candidate section for the proposed GSSP (Fig. 1). The base of Cambrian Series 3 within this section is marked by the FAD of *Oryctocephalus indicus*. $\delta^{13}C_{carb}$ data vary between −4.6 ‰ and −0.8 ‰, and $\delta^{34}S_{CAS}$ values range from −1.3 ‰ to 36.8 ‰. Again, similar positive $\delta^{13}C_{carb}$ excursions as documented at Molodo River characterize the boundary interval. The issue of note for Split Mountain is that both peaks occur in the *Olenellus–Eokochaspis nodosa* zones, in the uppermost *Amecephalus arrojosensis* Zone, and are thus situated below the FAD of *Oryctocephalus indicus* (Wotte et al. 2011). However, based on biostratigraphic information, these two positive $\delta^{13}C_{carb}$ peaks are probably correlative with the two positive $\delta^{13}C_{carb}$ excursions respectively below and above the FAD of *Ovatoryctocara granulata* at Molodo River.

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