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(Re)proposal of Three Cambrian Subsystems and Their Geochronology

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The Cambrian is anomalous among geological systems as many reports divide it into three divisions of indeterminate rank. This use of "lower", "middle", and "upper" has been a convenient way to subdivide the Cambrian despite agreement it consists of four global series. Traditional divisions of the system into regional series (Lower, Middle, Upper) reflected local biotic developments not interprovincially correlatable with any precision. However, use of "lower", "middle", and "upper" is unsatisfactory. These adjectives lack standard definition, evoke the regional series, and are misused. Notably, there is an almost 50 year use of three Cambrian subsystems and a 1997 proposal to divide the Avalonian and global Cambrian into four series and three subsystems. The global series allow proposal of three formal subsystems: a ca. 32.6 Ma Lower Cambrian Subsystem (Terreneuvian and Series 2/proposed Lenaldanian Series), a ca. 9.8 Ma Middle, and a ca. 10 Ma Upper Cambrian Subsystem (=Furongian Series). Designations as "Lower Cambrian Subsystem" or "global Lower Cambrian" distinguish the new units from such earlier units as "Lower Cambrian Series" and substitute for the de facto subsystem terms "lower", "middle", and "upper". Cambrian subsystems are comparable to the Carboniferous' Lower (Mississippian) and Upper (Pennsylvanian) Subsystems.

Introduction

The Cambrian Period (c. 538–487 Ma) is inarguably one of the most important intervals in Earth history. It featured modernization of the World Ocean with the origin and diversification of burrowing and mineralized metazoans at the onset of the Cambrian Evolutionary Radiation (CER, terminal Ediacaran–earliest Cambrian). The CER was followed by appearance of the earliest colonial eumetazoan groups characteristic of the Great Ordovician Diversification Interval (GOBI) about halfway through the Cambrian (e.g., Landing et al., 2010b, 2018). Following work by the International Subcommission on Cambrian Stratigraphy (ISCS), these key biotic developments can be related to the chronostratigraphic subdivision of the Cambrian System into four global series and ten stages (e.g., Babcock, 2005; Babcock and Peng, 2007) complemented by an increasingly precise U-Pb (numerical) geochronology (Fig. 1). This decision at the 2004 ISCS meeting meant that the traditional subdivisions of the Cambrian into regional "Lower," "Middle," and "Upper" series (discussed below) were no longer formal, but informal, adjectives. As such, they are uncapitalized as recommended by the International Stratigraphic Commission (e.g., Salvador, 1994, p. 97, 98). A consequent confusion is a continuing dual chronostratigraphic nomenclature—with the informal designations "lower", "middle", and "upper" Cambrian persisting in use in numerous reports either as complementary chronostratigraphic terms to the global four series or used by themselves to subdivide the Cambrian.

The latter approach that uses informal Cambrian divisions is widespread and includes studies on all of the Cambrian paleocontinents. These include West and East Gondwana (e.g., Compston et al., 2008; Álvaro et al., 2014; Betts et al., 2016, 2018), Laurentia (e.g., Knight et al., 2017), Baltica (e.g., Nielsen and Schovsbo, 2011), Avalonia (e.g., Landing, 1996; Fletcher, 2006), the South China Platform (e.g., Dong and Zhang, 2017), Siberian Platform (Kouchinsky et al., 2008; Zhuravlev et al., 2015; Zhuravlev and Wood, 2018), and also in global summaries (e.g., He et al., 2019).

Regular use of the informal and undefined designations "lower", "middle", and "upper" Cambrian has persisted for a generation after the 2004 decision to use formal series-level divisions. Their use demonstrates a need for these adjectives as convenient and useful chronostratigraphic terms. Rather than suppress them, a formal subdivision of the Cambrian into three subsystems with globally appropriate definitions should be adopted to standardize both the definition of its higher level chronostratigraphy and its nomenclature. Following the proposal in 1997 to the ISCS (Landing, p. 2, *in* Landing and Westrop, 1998; also Landing et al., 2013a–c, 2018), global "Lower", "Middle", and "Upper" Cambrian subsystems are formally (re)proposed in this report for discussion by the ISCS. Formal, global subsystems, that derive their definition from the existing Cambrian series are needed for convenient discussion of the system and do not confuse the evolving definitions of global Cambrian series.

Problems in Cambrian Chronostratigraphic Nomenclature

The informal (uncapitalized) adjectives "Lower", "Middle", and "Upper" evoke the traditional series-level divisions of the Cambrian (e.g., Robison et al., 1977). However, this report emphasizes that use of these informal adjectives is unsatisfactory for a number of reasons. First, they have no logical or established meaning in a system divided into four series.

An obvious question is what is "middle Cambrian" in a four-part succession? Is it the second and third series, or the third global series, which resembles in its meaning the earlier, traditional, regional Middle Cambrian Series? In addition, are the writer and readers of a report to think that "middle Cambrian" geochronologically implies the middle third of a Cambrian System with a ca. 50.8 Ma duration? If so, then "middle Cambrian" corresponds to a ca. 521.6–504.6 Ma time frame and then equates to most of Epoch 2/Proposed Lenaldenian Epoch and to the lower half of the Miaolingian Epoch (old informal Epoch 3) (Fig. 1).

Secondly, the three adjectives "Lower", "Middle", and "Upper" as used in many reports since 2004 must be regarded as representing a chronostratigraphic grade between the four global series (Babcock et al., 2005) and a system. Thus, they must be regarded as implying presently undefined subsystems.

Thirdly, without a standardized definition, their use may even be incorrect by any standard—such as the reference to the "upper Cambrian" of Drumian Stage strata (Dunk et al., 2019; Fig. 1) that are traditionally and invariably regarded as "middle Cambrian." Thus, "upper Cambrian" was incorrectly used in a widely distributed article by its authors, reviewers, and editors. This leaves the impression that a bipartite ("lower" and "upper") division of the Cambrian might actually have been intended.

Finally, widespread use of these uncapitalized, informal chronostratigraphic Cambrian divisions seems to have led to confusion in the designation of formal series-level units in other geologic systems. As an example, the three formally defined and capitalized Ordovician series (e.g., Ogg et al., 2008, fig. 5.4) are now commonly, and incorrectly, used as uncapitalized units (e.g., Saltzmann et al., 2015, their "lower" Ordovician) probably following the "example" of the uncapitalized terms "Lower", "Middle", and "Upper" Cambrian in other reports.

The Need for Formal Cambrian Subsystems

Regular use of "Lower", "Middle", and "Upper" Cambrian for a generation after the 2004 decision to use formal series-level divisions shows that they are "convenient and useful," albeit presently undefined chronostratigraphic terms. Furthermore, these informal adjectives are also practical ways to subdivide the Cambrian for presentations given to non-specialized general geology audiences and in teaching students.

The divisions "Lower", "Middle", and "Upper" cannot continue in use as informal, undefined, and, by implication, series-level units. For

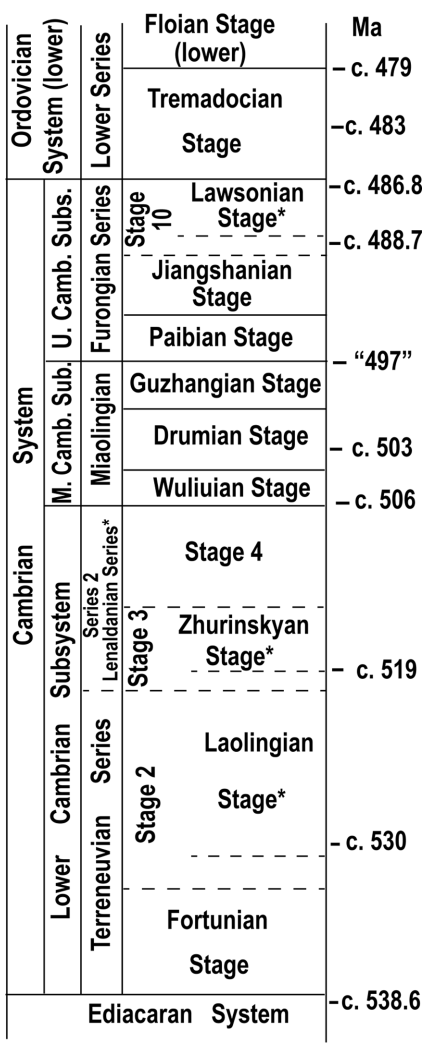

Figure 1. Cambrian global chronostratigraphy and geochronology showing three proposed Cambrian subsystems. Geochronology: Ediacaran–Cambrian boundary age (Linnemann et al., 2019) considered latest Ediacaran (see text). Date on uppermost Stage 3 from Harvey et al. (2011). C. 503 Ma date in Drumian from Landing et al. (2015a). Date on base of Cambrian Subsystem 3 and Miaolingian Series from Karlstrom et al. (2020). Guzhangian–Tremadocian dates differ from those in International Chronostratigraphic Chart (Cohen et al., 2013, updated 2019) as detailed in Landing et al. (2015a), with no evidence ever provided on "497 Ma" date on Paibian base (Cohen et al., 2013). C. 486.6 Ma date on base of Ordovician (Landing et al., 2015b) corrects date in International Correlation Chart and is best positioned stratigraphically just below base of Ordovician (see Landing et al., 2000). Asterisks (*) indicate proposed Laolingian Stage and Lenaldanian Series with lower Zhurinskyan Stage (detailed in Landing et al., 2013a–c); proposed Lawsonian Stage from Landing et al. (2010a, 2011) and Miller et al. (2011, 2018).

example, common use of "lower Cambrian" to include the Terreneuvian Series and informal Series 2/proposed Lenaldanian Series of Landing et al. (2007, 2013a–c, 2018) means that "lower Cambrian" comprises two series in many reports. Thus, it is best regarded as a "Lower Cambrian Subsystem" fide Landing (*in* Landing and Westrop, 1998a, p. 2) with the higher part of the system divided into proposed

Middle and Upper Cambrian subsystems defined with reference to the existing global series and stages (Landing et al., 2010b, 2018). This earlier suggested procedure follows Salvador (1994, p. 81) who noted that "special circumstances (suggest) the occasional need for subsystems…; for example, the Mississippian and Pennsylvanian Subsystems of the Carboniferous System."

Definition of the Cambrian

Historical Summary

The first insights into a scientific understanding of ancient Earth history took place in the early 19th century's "heroic age" of geology. This era included recognition that the sedimentary record had a seemingly 'azoic' interval overlain by rocks with a vertical succession of distinctive fossil assemblages (e.g., Geyer and Landing, 2016). This distinction was a background for the modern understanding of chronostratigraphy in that rock bodies represent an interval of geologic time and, consequently, can be regarded as geochronologic units.

Based on work in North Wales, Sedgwick (*in* Sedgwick and Murchison, 1835) coined one of the oldest named chronostratigraphic units by terming the apparently oldest fossil-bearing rocks the "Cambrian System." For a few decades this was problematical as his original concept of the Cambrian was based on rocks for which he could not name diagnostic fossils. Furthermore, his Cambrian System was shown to largely overlap Murchison's Silurian System (also proposed in the 1835 report), and it included units later shown to be late Precambrian–early Silurian in Wales.

Secord (1986; also Cowie et al., 1972) detailed that lower Paleozoic chronostratigraphy was stabilized by Lapworth's (1879) proposal of the Ordovician System, which provided upper and lower brackets on the Cambrian and Silurian systems, respectively. His proposal also allowed all three chronostratigraphic units (systems) to be used globally with the understanding that they implied time (geochronologic) intervals.

More recently, precise, globally correlative boundaries have been assigned to the Cambrian. With international agreement on definition of a Global Stratotype Section and Point (GSSP) for the base of the Ordovician (Cooper et al., 2001), the Tremadocian Stage, previously regarded as the top of the Cambrian particularly in British and Commonwealth reports that followed Lapworth (1879; Fig. 1), was assigned to the Ordovician. About a decade earlier in 1992, a GSSP was approved for the base of the Cambrian (Brasier et al, 1994; Landing, 1994; Geyer and Landing, 2016).

Three (and Four British) Cambrian Series

19th century reports variably proposed a bipartite (Lower and Upper) or tripartite (Lower, Middle, and Upper) subdivision of the southern British Cambrian succession (e.g., Cowie et al., 1972, fig. 1). The two- and three-fold division of the Cambrian and other geological systems likely reflects their early descriptions in western and central European languages that share convenient Indo-European words for bi- and tripartite divisions (e.g., Buck, 1949; Gamkrelidge and Ivanov, 1990). A tripartite division of the Cambrian was stabilized in the late 19th century only with improved understanding of the trilobite succession in Baltica, Laurentia, Avalonia (particularly North Wales and adjacent England, eastern Newfoundland, Maritime Canada, eastern Massachusetts), and the Bohemian region. In particular, Brøgger (1879) recognized faunas with *Paradoxides* above sparsely fossiliferous intervals with olenellid trilobites in Norway, and later (Brøgger, 1886) concluded that intervals with olenellids in North America (Laurentian and Avalonian) were older, not younger, than paradoxidid-bearing intervals. (However, see discussion below that lower paradoxidid-bearing intervals in Avalonia, West Gondwana, and the Siberian Platform are now understood to overlap in age with redlichiid- and olenellid-bearing intervals in South China and Laurentia).

In agreement with Brøgger's correlations, Walcott (1889, 1890) referred this underlying North American interval to what he called Lower Cambrian, which was also termed it the *Olenellus* Zone (successively designated the Georgian, Saratogan, and finally Waucoban Series; Walcott, 1891, 1912). Walcott (e.g., 1891) used "Middle Cambrian" for Laurentian strata that he correlated with the *Paradoxides* fauna-bearing interval in Baltica and Avalonia.

Without discussion and essentially by fiat, Walcott (1891, p. 370–379) recognized the Upper Cambrian across Laurentia and globally as an interval above paradoxidid-bearing and coeval Middle Cambrian strata. Walcott's (1891) Upper Cambrian of Baltica and Avalonia included strata with "*Olenus* Zone" trilobites and also the somewhat similar interval (i.e., olenid-bearing) of the overlying "lower Tremadoc." Thus, Walcott's (1891) Cambrian consisted of three series, with the Upper Cambrian including the Tremadocian. An alternative chronostratigraphic approach followed by Scandinavian workers was a more abbreviated Upper Cambrian Olenid Series with the "Tremadoc Series" assigned to the Ordovician and with the *Agnostus pisiformis* Zone, with the lowest known olenid, assigned to the base of the Olenid Series (e.g., Westergård, 1922; Henningsmoen, 1957). Finally, another chronostratigraphic alternative in British and many Commonwealth reports featured inclusion of the "Tremadoc Series" in the Cambrian, which meant that the Cambrian consisted of four series: formally named Lower, Middle, and Upper units named for geographic type areas, but with the Upper Cambrian unit (Merioneth Series) grouped with the "Tremadoc Series" to form the Upper Cambrian (Cowie et al., 1972).

Avalonia and the First Named Cambrian Subsystems

The British practice of assigning the Tremadocian Series to the Cambrian (Lapworth, 1879) led Cowie et al. (1972, pls. 1–6) to outline, perhaps unwittingly and without discussion, three Cambrian subsystems. Cowie et al.'s (1972, p. 8) "British major divisions within the Cambrian" included their newly named Comley and St. David's series, which they termed "Lower" and "Middle" Cambrian, succeeded by their "Merioneth Series" and then the "Tremadoc Series." These four series were named from Avalonian Wales and England.

Significantly, the Merioneth and Tremadoc series were grouped and termed "Upper Cambrian" (e.g., Cowie et al., 1972, pl.1), which means their "Upper Cambrian" interval is composed of two series and consequently must be regarded as a subsystem. This "Upper Cambrian" unit (i.e., Merioneth plus Tremadoc series) has the same rank as the

"Lower Cambrian" assignment of the Comley Series and the "Middle Cambrian" St. David's Series in the correlation figures in Cowie et al. (1972, pl. 1–6), which in turn means these two lower series logically comprise two Cambrian subsystems. In short, the British Cambrian was outlined in a British Geological Survey-sanctioned publication to consist of three subsystems.

A similar approach that includes Cambrian subsystems was outlined for the four series proposed for the very similar Cambrian successions of Avalonian North America (discussed below; see Landing et al., 1989, 2013a–c, 2018; Landing, 1992). In these latter reports, the "Comley Series" was divided into a subtrilobitic Placentian and overlying trilobite-bearing Branchian series, which were both assigned to a "Lower Cambrian" subsystem. Higher strata included the Acadian and Merionethian series that were referred to the Middle and Upper Cambrian subsystems, respectively (Landing, 1996, figs. 2, 5, 7).

Four (Even Five) Regional Series and Three Cambrian Subsystems

As outlined above, the division of the Cambrian into series in the late 19th century was based on trilobites. Matthew (1889a, b) detailed a more thorough understanding of the lowest Cambrian by documenting a "Basal Series" with trace and shelly fossils below the lowest trilobites in Avalonian southern New Brunswick and eastern Newfoundland. Restudy of the New Brunswick fossils (Hofmann and Patel, 1988; Landing and Westrop, 1998b, p. 58–61; Landing, 2004) emphasizes that Matthew's (1889a, b) assignment of the "Basal Series" to the lowest Cambrian (i.e., Fortunian Stage of the Fortunian–Stage 2/ proposed Laolingian Stage of Landing et al., 2013a–c) was correct. With the Cambrian consisting of three successive trilobite-based series in regional syntheses of Laurentia, Baltica, and British Avalonia by the late 1800s (discussed above), documentation of an older "Basal Series" implied a "natural" four-fold division of the Cambrian.

Unfortunately, Walcott (1890, p. 544) dismissed Matthew's work by including the "Basal Series", despite its lack of trilobites, in his Lower Cambrian *Olenellus* Zone. Matthew (1899) later restated the faunal distinctiveness and temporal significance of what he now called the Etcheminian Series, but this synthesis was disregarded. His argument for the Etcheminian as a sub-Cambrian and lowest Paleozoic unit (Matthew, 1899) meant that he came to regard the Cambrian as tripartite with its series defined by trilobites.

The "Etcheminian Series" fauna is broadly similar to the subtrilobitic Nemakit-Daldynian and Tommotian stages of Siberia and the Meishucunian Stage of South China (Landing et al., 1987, 1988a, b). Thus, this concept provided the stimulus for a four-fold, series-level subdivision of the Avalonian Cambrian (Landing et al., 1989). This included a sub-trilobitic lowest Cambrian Placentian Series with its upper part shown to be coeval with trilobite-bearing strata in Siberia (e.g., Landing and Kouchinsky, 2016), The Placentian Series was united with an overlying trilobitic-bearing upper Lower Cambrian Branchian Series to form a Lower Cambrian Subsystem. The higher Acadian, and Merionethian series, respectively, were termed Middle, and Upper Cambrian series and subsystems (Landing et al., 1987, 2018; Landing, 1992, 1996).

A similar four-fold regional series succession was proposed for the Laurentian Cambrian by Fritz (1991), who applied the designation of the Avalonian subtrilobitic Placentian Series to the Canadian Cordillera and used the traditional Laurentian Waucoban, Albertan, and Croixan series for the successive trilobite-bearing, lower–middle–upper parts of the system, respectively.

Similarly, Palmer (1998) divided the Laurentian Cambrian into four series based on Great Basin and southern Canadian Rocky successions. These included his subtrilobitic Begadean Series and three trilobite-bearing lower–middle–upper divisions assigned to the vertically successive Waucoban, Lincolnian, and Millardian series. Palmer (1998) also included part of a fifth series, the lower part of Ross et al.'s (1997) Ibexian Series, as the uppermost Cambrian.

The convenience of using the traditional terms "Lower" (for the combined sub-trilobitic and Waucoban series), "Middle" (Albertan and Lincolnian series) and "Upper" (Croixan and Millardian–lowest Ibexian series) Cambrian by Fritz (1991) and Palmer (1998) meant that their highest level Cambrian subdivisions were three (unacknowledged) subsystems. This ranking of chronostratigraphic units follows the nomenclatural recommendations of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005) and International Stratigraphic Commission (Salvador, 1994).

Global Cambrian Series and Subsystems

History of Proposal

The proposal of four Cambrian series to the ISCS in 1997 (Landing, 1998a, p. 2) preceded Peng's (2004) proposal. The 2004 date typically reported as the first suggestion of a quadripartite Cambrian with four series (e.g., Babcock et al., 2005; Babcock and Peng, 2007; Rushton et al., 2011, p. 1; Zhu et al., 2018) only slightly preceded publication of the acceptance of the Furongian Series, with a lowest Paibian Stage, as the fourth and uppermost division of the Cambrian.

The decision to define global Cambrian series and stages followed from the long understanding (e.g., Robison et al., 1977) that independent and regional, and consequently confusing, concepts of the Lower, Middle, and Upper Cambrian existed in regions such as Avalonia, Baltica, Siberia, South China, and Kazakhstania. These differing series-level divisions of the Cambrian reflected long-term faunal provincialism and consequently highly distinct biotic successions on widely separated and climatically distinct Cambrian continents (e.g., Landing et al., 2013a, fig. 2 paleogeography). As a result, highly resolved global correlations were difficult even for regional Cambrian series (Geyer and Shergold, 2000)—an example being the problematical correlation of Öpik's (1967) Australian Ordian Stage into the Lower–Middle Cambrian boundary intervals of other faunal provinces. This meant that an alternative succession of globally correlative Cambrian series and stage had to be defined.

The decision to define global series-level units definitely was not a geochronologic need to replace the traditional, regional (Lower, Middle, Upper) series, which had very different durations, with four series of "subequal duration" (*fide* Babcock and Peng, 2007, p. 62). Indeed, existing geochronologic evidence had decisively shown (Isachsen et al., 1994; Landing et al., 1997, 1998, 2000) that the four series advocated in 2004 (Babcock et al., 2005) had very different and certainly not "subequal" durations. In any case, it is an error to advocate for establishing chronostratigraphic units of "subequal duration" when the North American and international stratigraphic codes have no such recommendation (Salvador, 1994; North American Commission on Stratigraphic Nomenclature, 2005). Furthermore, existing system-level units as the Quaternary are a fraction of the length of units such as the Cretaceous System (ca. 4%, e.g., Ogg et al., 2008). Similarly, the need to recognize "evolutionary events" to define alternative Cambrian series (Babcock and Peng, 2007, p. 63) provides no objective basis to abandon the traditional regional series. This is particularly the case as the tie lines that have been recognized to define the new chronostratigraphic units (i.e., series and stages in Babcock and Peng, 2007) are based on lowest local occurrences of taxa and not interpreted, and thus subjective, evolutionary events (e.g., Landing et al., 2013a, see discussion of "FADs").

The demonstrated need for and long-term use (since 1972) of Cambrian subsystems have been discussed above. In many ways, Babcock and Peng (2007, p. 65) anticipated the use of global Cambrian subsystems in noting the ISCS' "lower two series together will correspond roughly to the Lower Cambrian of traditional usage", and thus to the global Lower Cambrian Subsystem as advocated by Landing (*in* Landing and Westrop, 1998a). Similarly, Babcock and Peng's (2007, p. 65) "third Cambrian series will correspond roughly to the Middle Cambrian of some regional correlation schemes" and thus is similar to the regional Avalonian Middle Cambrian Subsystem (Cowie et al., 1972; Landing, 1998a, b) and corresponds precisely to the global Middle Cambrian Subsystem of Landing et al. (2013a, 2018). Finally, "the uppermost series (the Furongian Series) corresponds to the … [Upper Cambrian] as used in South China … and … Kazakhstan" (Peng and Babcock, 2007, p. 65) and to the proposed global Upper Cambrian Subsystem of Landing et al. (2015, 2018).

Proposal of Cambrian Subsystems and Subperiods

A global subsystem/subperiod division of the Cambrian includes three intervals: 1) the global Lower/Early Cambrian Subsystem and Subperiod consists of the Terreneuvian Series/Epoch and Series/Epoch 2 (i.e., proposed Lenaldanian Series/Epoch of Landing et al., 2013a, c); 2) a global Middle/Middle Cambrian Subsystem and Subperiod equivalent to the Miaolingian Series/Epoch; and 3) a global Upper/Late Cambrian Subsystem and Subperiod equivalent to the Furongian Series/Epoch (see discussions in Landing, 1998a, 1998b; Landing et al., 2010a, b, 2012a–c, 2013a–c, 2015, 2018). The three subsystems/subperiods are named for their position in the Cambrian System/Period and are defined with reference to the existing ISCS global series. As the global Lower–Upper Series of the Ordovician, they do not require a name that designates a geographic type locality.

Nomenclatural Uniqueness of Formal Cambrian Subsystems and Subperiods

An objection to the use of three global Cambrian subsystems based on potential confusion with the traditional, regional three series-level Cambrian divisions is not an argument against their adoption. Indeed, "Lower Cambrian Subsystem", "Middle Cambrian Subsystem", and "Upper Cambrian Subsystem" specify that these chronostratigraphic units are subsystems and distinct from the traditional Cambrian series. Similarly, the terms "Early Cambrian Subperiod", "Middle Cambrian Subperiod", and "Late Cambrian Subperiod" all indicate that these units are not Cambrian epochs. Furthermore, additional terms such as "global Lower Cambrian", "Lower Cambrian (g [with "g" an abbreviation for global])", "global Early Cambrian", and "Early Cambrian (g)" are additional ways to specify that a subsystem or subperiod, not a traditional Cambrian series or epoch, is designated.

This (re)proposal of Cambrian subsystems and subperiods ends with definitions of and comments on these chronostratigraphic and geochronologic units. These brief notes can be complemented by Geyer's (2019) summary of Cambrian local and global series and stages and their relationship to regional biostratigraphic successions on all Cambrian paleocontinents.

Lower Cambrian Subsystem and Early Cambrian Subperiod

The base of the proposed Lower Cambrian Subsystem defines the top of the Ediacaran System and corresponds to the GSSP for the coterminous bases of the Cambrian System and Terreneuvian Series at Fortune Head, Burin Peninsula, eastern Newfoundland (Narbonne et al., 1987; Brasier et al., 1994; Landing, 1994, Landing et al., 2007). Landing et al. (2013c; also Geyer and Landing, 2016) proposed to the ISCS that the GSSP remain precisely at the horizon accepted in 1992 but redefined as lying at the base of the *Treptichnus pedum* Assemblage Zone (not "FAD" of *T. pedum*). This horizon is defined by the highest occurrence of Ediacaran aspect problematica (i.e., *Harlaniella* and *Palaeopaschichnus*) in the lower range of *T. pedum*. The concept and use of the "Lower Cambrian Subsystem" would be maintained as the lowest subsystem of the Cambrian even if subsequent consensus leads to modification in definition of the base of the Cambrian and Ediacaran–Cambrian boundary.

A precise age of the base of the Cambrian remains problematical, and recent work suggests that the persistent "younging" of the base of the Cambrian (Landing et al., 1998a) continues. It is possible that Linnemann et al.'s (2019) age of 538.6–538.8 Ma on the Ediacaran–Cambrian boundary may be too old as the lower biostratigraphic bracket they tentatively assign to the Cambrian is an association of *Treptichnus* cf. *pedum* and *Streptichnus narbonnei*. They term this a "Cambrian-type ecosystem", although *S. narbonnei*'s range is essentially unknown because it is known only from small collections in the boundary-interval succession in Namibia. In addition, their *T.* cf. *pedum* provides limited biostratigraphic resolution in the Ediacaran–Cambrian boundary interval as *T. pedum*-type traces are commonly believed to appear in the terminal Ediacaran. Linnemann et al.'s (2019) 538.6 Ma ash occurs just below a horizon with *T. pedum*, which by itself may mark a terminal Ediacaran interval (e.g., Landing et al., 2013c; Geyer and Landing, 2016). For this reason, a date of 538.6 Ma may be referable to the terminal Ediacaran and this would mean an even younger age for the base of the Cambrian (Fig. 1).

The upper part of the Lower Cambrian Subsystem includes the trilobite-bearing intervals traditionally brought to the "Lower Cambrian Series" on a number of paleocontinents. It also includes coeval, but locally subtrilobitic units in Avalonia (Landing and Kouchinsky, 2016).

These include the Hartshill Member and "*Obolus groomi* beds" in the upper part of Cowie et al.'s (1972) British 'Non-Trilobite' Zone and the upper Cuslett Formation and Fosters Point Formation in North America (see Landing, 1996, Landing et al., 2013a). As the lowest occurrence of Cambrian trilobites invariably lies at facies changes and unconformities worldwide (Landing et al., 2013a, 2020; Geyer, 2019), the "FAD of trilobites" cannot be used as a basis to define the base of a Cambrian Series 2 as repeatedly promoted by the ISCS (e.g., Peng and Babcock, 2008, table 4.1). An age of ca. 519 Ma lies within the lowest range of mineralized trilobite remains in Avalonia and Moroccan West Gondwana (Landing et al., 2013d, 2020; Fig. 1).

With the age of the base of the Middle Cambrian Subsystem at about 506 Ma (discussed below), the ca. 32.6 Ma length of the Lower Cambrian Subsystem is far longer than the other two subsystems. The approximate duration of the Terreneuvian Series and Series 2/proposed Lenaldanian Stage at ca. 19.6 Ma and 13 Ma, respectively, emphasizes that the ISCS plan for a succession of series of "subequal length" (Babcock and Peng, 2007) was not fulfilled following scientific study.

Middle Cambrian Subsystem and Middle Cambrian Subperiod

The base of the proposed Middle Cambrian Subsystem defines the top of the Lower Cambrian Subsystem. In turn, the top of the new subsystem is the base of the proposed Upper Cambrian Subsystem. The Middle Cambrian Subsystem roughly corresponds to the traditional Middle Cambrian Series on a number of paleocontinents, and its base approximates the traditional and roughly correlative bases of the Middle Cambrian Series in Laurentia and in South China (e.g., Geyer, 2019; Karlstrom et al., 2020). In the latter area, the cotermінent bases of the global Miaolingian Series and Wuliuan Stage at Balang, Guizhou Province, China, are defined by the lowest occurrence of the trilobite termed *Oryctocephalus indicus* (Esteve et al., 2017; Zhao et al., 2018, 2019; Peng and Zhou, 2018). This GSSP horizon also defines the base of the proposed Middle Cambrian Subsystem (Fig. 1). The top of the Miaolingian Series is defined by the base of the Furongian Series and the base of the Furongian corresponds to the base of the proposed Upper Cambrian Subsystem (discussed below). Thus, the Middle Cambrian Subsystem brackets the Miaolingian Series and its Wuliuan, Drumian, and Guzhangian stages (i.e., Zhou et al., 2019). The concept and use of the proposed "Middle Cambrian Subsystem" would be maintained as the middle subsystem of the Cambrian even if subsequent consensus leads to modification in definition of the base of the third global series (i.e., Miaolingian or its replacement).

Definition of the base of the Miaolingian means assignment of the lower part of the traditional Middle Cambrian *Paradoxides* (s.l.)-bearing strata of Avalonia, West Gondwana (Morocco and Iberia), and the Siberian Platform to the Lower Cambrian (i.e., Sundberg et al., 2016; Sundberg, 2018; Geyer, 2019; Karlstrom et al., 2020). Unfortunately, this obviates all of the earlier literature on the definition of the base of the traditional lower Middle Cambrian Series on all Cambrian paleocontinents (e.g., Geyer and Palmer, 1995; Geyer and Shergold, 2000). Similarly, the proposed global Middle Cambrian Subsystem would not include these lower parts of the traditional Middle Cambrian of Avalonia, West Gondwana, and the Siberian Platform.

A highly resolved geochronology does not exist for the base of the Miaolingian Series and Middle Cambrian Subsystem. Volcanic ashes or other datable material do not occur in the GSSP section. Zhou et al.'s (2019) assignment of a 509.1 ± 0.22 Ma age to the Miaolingian base followed from the assumption that the basal Miaolingian correlated into the traditional basal Middle Cambrian of Avalonia. Thus, they used Harvey et al.'s (2011) 509.1 ± 0.22 Ma age determined on a single zircon from the (presumed lowest) *Acadoparadoxides harlani* Zone in Shropshire as the date on the base of the Miaolingian.

An obvious caveat to Zhou et al.'s (2018, 2019) age on the base of the Miaolingian is that the English zircon came from a basal sandstone unit (Quarry Ridge Grit) that that underlies fossil-bearing and biostratigraphically datable strata. The Quarry Ridge Grit itself unconformably overlies the biostratigraphically problematical (upper Lower or lower Middle Cambrian?), very thin *Lapworthella* Limestone (i.e., Landing, 1996). Thus, the zircon may be reworked. This interpretation is made more plausible by Schmitz's (2012a, b) recalculation of the 511 ± 1.0 Ma date (Isachsen et al., 1994) recorded from the traditional upper Lower Cambrian (*Protolenus elegans* Zone) of the Hanford Brook Formation in Avalonian New Brunswick as 508.05 ± 2.5 Ma. The New Brunswick and Shropshire dates are identical within the limits of error. It must be emphasized that the New Brunswick ash lies below a major unconformity with the middle part of the traditional Middle Cambrian (Landing, 1996) and that the Lower Cambrian Subsystem includes much younger strata (e.g., Karlstrom et al., 2020).

A second caveat on the age of the basal Miaolingian derives from the likelihood that the base of the series correlates into strata higher than the lower *Paradoxides*(s.l.)-bearing interval of Avalonia (Sundberg et al., 2016; Geyer, 2019; Karlstrom et al., 2020). This means that the ca. 509 Ma date from Shropshire, even if the zircon grain is not reworked, must be too old for the base of the Miaolingian and a Middle Cambrian Subsystem.

Since the late 19th century, paradoxidid-bearing strata have defined regional concepts of the Middle Cambrian (discussed above). However, reevaluation of all available evidence now supports the interpretation that early paradoxidids were contemporaneous with later Laurentian olenellid and South China redlichiid faunas. What this means is that olenellid- and redlichiid-bearing faunas persisted and disappeared in low latitude faunal provinces in the same time interval that paradoxidiids and associated taxa were appearing in higher latitude regions (Geyer and Palmer, 1995; Fletcher et al., 2005; Fletcher, 2006; Sundberg et al., 2016; Geyer, 2019; Karlstrom et al., 2020). This would mean that the base of the Miaolingian and its GSSP defined by the "FAD" of *Oryctocephalus indicus* is younger than the highest olenellids in western Laurentia (Sundberg, 2018; Karlstrom et al., 2020).

With the determination of dates of ca. 506.5 Ma on detrital zircons from the Tapeats Sandstone below the highest *Olenellus* Zone s.l. faunas in Arizona (Karlstrom et al., 2020), an estimated age of 506 Ma on the base of the Miaolingian Series (Karlstrom et al., 2020) and proposed Middle Cambrian Subsystem seems more appropriate (Fig. 1). With a ca. 497 Ma age assigned to the base of the Paibian Series and proposed Upper Cambrian Subsystem (discussed below), the Miaolingian Series and proposed Middle Cambrian Subsystem have a relatively short duration of ca. 9.8 Ma (Fig. 1).

Upper Cambrian Subsystem and Late Cambrian Subperiod

The base of the proposed global Upper Cambrian Subsystem defines the top of the Middle Cambrian Subsystem, and the top of the new subsystem is the base of the Ordovician System (see Cooper et al, 2001). The Upper Cambrian Subsystem corresponds chronostratigraphically to the global Furongian Series, with its base corresponding to the coterminent GSSP for the bases of the Furongian Series and Paibian Stage (Fig. 1). This GSSP is defined by the lowest occurrence of the agnostoid arthropod *Glyptagnostus reticulatus* at the Paibi section in northwestern Hunan Province, China (Peng et al., 2004). The concept and use of the designation "Upper Cambrian Subsystem" would be maintained as the uppermost subsystem of the Cambrian even if subsequent consensus leads to modification in definition of the bases of the Furongian Series and Ordovician System.

This definition means that the Upper Cambrian Subsystem is somewhat truncated by comparison with the lowest parts of the traditional Upper Cambrian Series on a number of paleocontinents. This lowest traditional Upper Cambrian has been reassigned to the upper part of the Middle Cambrian Subsystem and Miaolingian Series with definition of a basal GSSP for the Furongian Series. Briefly listed, the lower Franconian Stage of the upper Mississippi River valley (Laurentia), the Australian (East Gondwanan) Mindyallan and Boomerangian stages, and the *Agnostus pisiformis* Zone of Avalonia and Baltica are now assigned to the Miaolingian.

The duration of the Late Cambrian Subperiod is problematical, but it seems to be the shortest subperiod of the Cambrian. Little geochronologic work has been published on the interval since the review by Landing et al. (2015b). No precise geochronological work has been done on the Middle–Upper Cambrian Subsystem boundary interval, and the subsystem can only be bracketed as having a duration of approximately 10 Ma.

Somewhat distressingly, the age of the top of the Cambrian (and Cambrian Subsystem) and base of the Ordovician is incorrect in almost all publications. Thus, a 485.4 ±1.9 Ma date appears in the ICS charts (Cohen et al., 2013, and updates through 2019) and in derivative publications (e.g., Zhu et al., 2018). However, Landing et al. (2015b) detailed that Schmitz (2012a, b) recalculated the terminal Cambrian date of Landing et al. (2000; 489 ± 0.6 Ma) to 486.78 ± 0.53 Ma. For this reason, a ca. 487 Ma date is set just below the Ordovician in Fig. 1.

The source of the 497 Ma date for the base of the Upper Cambrian Subsystem and Paibian Series (Peng and Babcock, 2008; Zhu et al., 2018) has long remained unknown, although it is repeated by Cohen et al. (2013 and updates). The available evidence indicates the Middle–Upper Cambrian Subsystem boundary can only be bracketed by U-Pb zircon dates of 494.4 ± 3.5 Ma in theDrumian (Landing et al., 2015a) and 488.71 ± 1.17 Ma just below the proposed Lawsonian Stage (see Landing et al., 2010a, 2011, 2015).

Conclusions

The informal terms "lower," "middle," and "upper" have persisted as convenient and natural divisions of the Cambrian since the 2004 agreement to divide the system into four global series. The continued use of three informal divisions of a geological system (as well as of a period, i.e., "early", "middle, "late" Cambrian) is unique to and is an anomaly of the Cambrian as unit divisions of all other systems/periods are formally defined intervals (i.e., Lower, Middle Upper divisions of the Ordovician, Devonian, Triassic, and Jurassic; Lower and Upper Cretaceous).

These undefined, informal adjectives used to bracket the Cambrian have an indeterminate chronostratigraphic rank/significance. Thus, "lower Cambrian" is a de facto subsystem as it includes an exceptionally long interval bracketing the Fortunian Series and Series 2/proposed Lenaldanian Series. By comparison, the "middle" and "upper" Cambrian of informal usage roughly correspond to two formally named, much shorter global series. However, their use invokes the traditional "Middle" and "Upper" Cambrian regional series earlier specifically defined for each Cambrian paleocontinent.

There is an easy way out of this nomenclatural problem that would not only facilitate communication with students and non-professionals unfamiliar with global series names that are not intuitively meaningful but also roughly corresponds to almost 200 years of literature that used a tripartite division of the Cambrian. Almost 50 years ago, Cowie et al. (1972) divided the Avalonian Cambrian into four regional, series-level units, but grouped them into three higher-level chronostratigraphic units that correspond to regional subsystems. This report takes a similar approach in (re)proposing subdivision of the Cambrian into three, precisely defined global subsystems/subperiods that cannot be confused with any of the three obsolescent regional series. This approach, which is comparable to the subsystem/subperiod division of the Carboniferous, proposes a "Lower/Early Cambrian Subsystem/Subperiod (S/S)" or "global Lower/Early Cambrian" equivalent to the Fortunian–Series 2/proposed Lenaldanian Series, a "Middle Cambrian S/S" or "global Middle Cambrian" equivalent to the Miaolingian Series, and an "Upper/Late Cambrian S/S" or "global Upper/Late Cambrian" equivalent to the Furongian Series.

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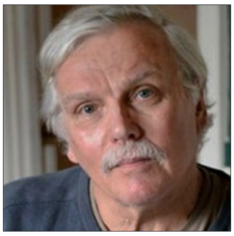

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