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Phanerozoic Chronostratigraphy: Top-Down Instead of Bottom-Up Boundary Definitions †

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Abstract: The GSSP method defines stage bases, and, where proximate, equates them to the bases of larger chronostratigraphic units. The Phanerozoic and its subdivisions above the stage level thus are only successively larger "pigeonholes" within which to bin stages. This reductionism trivializes chronostratigraphic boundaries larger than stage boundaries. A single set of standard global stages is an unworkable abstraction that should be abandoned because no stage can be correlated globally because of facies changes, taphonomic biases, and/or provincialism. Stratigraphers should return to a top-down chronostratigraphy that defines chronostratigraphic units larger than stages by significant natural events that can be correlated globally.

Keywords: Phanerozoic; chronostratigraphy; GSSP; reductionism; stage; series; system; eonothem

1. Introduction

Since the 1960s, the Phanerozoic chronostratigraphic scale has been defined/redefined by the method of Global Stratotype Sections and Points (GSSPs) (see [1–6] for reviews of the GSSP method). The GSSP method defines stage bases, and, where proximate, equates them to the bases of larger chronostratigraphic units. The recognition of a single set of global stages is also one of the cornerstones of the GSSP method, though no stage can be correlated globally. Here, I argue that the GSSP method embodies a reductionism that trivializes the boundaries of chronostratigraphic boundaries larger than stages. Stratigraphers should return to a top-down chronostratigraphy that defines chronostratigraphic units larger than stages by significant natural events with potential for global correlation.

2. Can We Recognize "Global Stages?"

The International Commisssion on Stratigraphy (ICS) recognizes 102 Phanerozoic stages; in 2018, 71 of these stage bases had ratified GSSPs [7]. These are the so-called "global standard stages" that are the chronostratigraphic equivalents of corresponding, relatively short global intervals of time, the ages. A single set of global stages is a hallmark of what some call the "Hedbergian stratigraphy", and is one of the cornerstones of the GSSP method. Hedberg [1] (p. 71) recognized this in the first edition of the *International Stratigraphic Guide*, stating that the stage "is one of the smallest units in the standard chronostratigraphic hierarchy that in prospect may be recognized worldwide." However, Hedberg [1] (p. 76) had doubts about the global recognition of stages, emphasizing that "the systems are generally recognized worldwide; series usually so; but units of lower rank are at present commonly of only regional or local application, although their recognition worldwide is a goal." Nevertheless, in the second edition of the *International Stratigraphic Guide*, the stage was identified as "the smallest unit in the standard chronostratigraphic hierarchy that can be recognized at a global scale" [4] (p. 78), and, in 1996, the ICS leadership [3] (p. 86) stated, "the lower boundaries of chronostratigraphic units of higher rank (series, systems etc.) are automatically defined by the base of their lowermost stage."

Stage bases are defined in marine strata, usually with their primary signal the supposed FAD (first appearance datum) of a marine pelagic organism, so how can such stages be recognized in other facies where the primary signal is not present (especially non-marine facies) or in provinces in which the organism did not live? There are ways to correlate across facies and provincial boundaries, but at the stage level these correlations are often imprecise. In theory, the standard global stage represents a time interval, but that is all that is global about it. The idea of standard stages that can be applied globally is thus an abstraction that should be abandoned.

Only the systems and erathems of the Phanerozoic Eonothem have proven to be of unquestioned global utility. Most of the Phanerozoic series have also been recognized globally, though there are serious problems with the global recognition of some. Most striking has been whether to recognize the Mississippian and Pennsylvanian as the two Carboniferous series. After decades of debate, these concepts were ratified by ICS as "subsystems" [8], even though in Western Europe and Russia they are not the most logical divisions of the Carboniferous System. Indeed, the Carboniferous System is also exemplary of the inability to recognize global stages [9,10].

All of the Phanerozoic systems have multiple sets of regional stages that reflect historical, provincial, and facial characteristics of that system. Many of these stages continue to be recognized, simply because they are useful to age assignment and correlation. Instead of searching for global stages, each ICS subcommission should identify a finite number of regional stages and focus on defining and correlating them to each other. This will produce realistic (workable) stages for Phanerozoic chronostratigraphy.

3. Should We Continue Chronostratigraphic Reductionism?

Reductionism reduces complex phenomena to the sum of their constituent parts, in order to make them easier to study, and plays an important role in science as a way to break down complex phenomena into their components. The GSSP method employs hierarchical reductionism by reducing each chronostratigraphic boundary to the boundary of the lowest unit in the chronostratigraphic hierarchy, the stage.

GSSPs of stages have generally been associated with and correlated by a "primary signal" that is a very minor event, in many cases the origin of a microfossil species. Most primary signals are the FAD of a fossil taxon; however, as already noted, all of these fossils are subject to restrictions on the basis of provinciality, facies, and taphonomy. Furthermore, the origin and dispersal of any biological species is inherently diachronous. This is why some (e.g., [5]) have argued that more GSSPs should be defined by non-biological criteria, such as magnetostratigraphic reversals and isotope excursions. However, most of these criteria cannot be uniquely recognized or correlated without bracketing biostratigraphic datums or radioisotopic ages.

Given that the hierarchical reductionism of the GSSP method equates the boundaries of chronostratigraphic boundaries larger than stages, to stage boundaries, why recognize and use larger chronostratigraphic divisions? Indeed, the term Phanerozoic and its subdivisions above the stage level have no particular significance other than as successively larger "pigeonholes" within which to bin stages [2,6].

The Phanerozoic systems and erathems were mostly established by 1850 on the basis of ideas similar to the concept of periodization used by historians of human history (e.g., [11]). To those who created the geological time periods, each encompassed a succession of strata with fossils distinct from those of other periods. As Murchison [12] (p. 6) said with regard to the Silurian, "I became convinced that, as this large and ancient group [of strata] contained peculiar organic remains, and was marked by distinctness of physical features, lithologic structure, and order of superposition, it was well entitled to be considered a separate *system* [Silurian]."

To students of human history, periodization is the process of organizing the past into named blocks of times called periods, eras, stages, or ages. Periodization "subdivide[s] it [history] into manageable and coherent units of time" [11] (p. 13). It is through significant events that historians organize human history, and geological history should be no different. The reason periodization worked so well in stratigraphy is because Earth history is more than a succession of FADs of marine pelagic organisms or the other minor events used as primary signals of most stage-based GSSPs [2]. As Cloud [13] (pp. 537–538) precisely stated, "it becomes necessary in all historical science to identify events or broad modalities that set off one part of the sequence from preceding and following parts so as to bring out historical trends." When we organize the stratigraphic record on the basis of such events or modalities, the resulting classification imparts more information (e.g., base ofTriassic—mass extinction, Mesozoic—"age of reptiles", base of Eocene—global greenhouse) than the information contained in a reductionist chronostratigraphy that organizes Earth history only by stages [14–15].

4. An Example: The Base of the Phanerozoic Eonothem

In the reductionist GSSP-based chronostratigraphy, the base of the Fortunian Stage also defines the bases of the Terreneuvian Series, Cambrian System, Paleozoic Erathem, and Phanerozoic Eonothem. Geyer and Landing [16] provide a detailed review of the history of defining the base of the Cambrian. Most 19th century workers regarded the Cambrian base as the boundary between rocks with fossils above older rocks without fossils, but in the 20th century the idea that the FAD of trilobites marked the base of the Cambrian became popular, followed by efforts to define the base by the first appearance of small shelly fossils. In 1972, the Cambrian Subcommission organized a working group on the Precambrian–Cambrian boundary. Three possible signals of a Cambrian base found advocacy: (1) FAD of "small shelly fossils" (SSFs), also called the Tommotian fauna or "early skeletal fossils" (ESFs); (2) FAD of trilobites; and (3) a trace fossil FAD. However, the small shelly fossils were shown to have marked provincialism as well as restriction to carbonate facies. For similar reasons, the FAD of trilobites was swept aside [17].

However, instead of identifying the most likely FADs of these classic criteria by which the base of the Cambrian had long been defined, the focus switched to using trace fossils for boundary definition. This was done despite the fact that trace fossils characteristically have long stratigraphic ranges and are facies controlled, and thus they have never had substantial biostratigraphic utility. Furthermore, the trace fossil record began in the Ediacaran; thus, the idea that a major innovation in behavior marked by the trace fossil record could be used to define the Cambrian base is questionable.

In 1992, a basal Fortunian GSSP was ratified at the Fortune Head section in Newfoundland, Canada, with the primary signal the "FAD" of the trace fossil taxon *Treptichnus* (= *Trichophycus*) *pedum* [18]. However, less than a decade after ratification, the stratigraphic range of *T. pedum* at Fortune Head was extended about 4 meters lower than the GSSP level [19]. Thus, the GSSP for the base of the Fortunian (Cambrian, etc.) needed to be redefined.

Landing et al. [20] argued that FADs are inherently diachronous, downplaying the fact that if the LO (lowest occurrence) chosen for GSSP definition is not the FAD of the taxon (clearly the case with *Treptichnus pedum* at Fortune Head), then the choice of GSSP level was simply a mistake. Geyer and Landing [16] also claimed that the record of Cambrian *T. pedum* was "evolutionarily controlled rather than facies controlled" [21] (p. 519), even though the simple fact that the trace is not known from early Cambrian carbonate rocks indicates obvious facies control of its distribution. Indeed, *Treptichnus* is a temporally long-ranging trace with multiple potential makers, and a facies crosser later in its record [22]. Its Cambrian facies restrictions are to a "shallow marine clastic setting" [21], similar to the much younger and widespread trace *Ophiomorpha* (a crustacean burrow), yet nobody uses *Ophiomorpha* in biostratigraphy or chronostratigraphy. Indeed, other than the base of the Fortunian, no trace fossil has ever been used as the primary signal of a Phanerozoic GSSP. Clearly, using the FAD of trilobites or of early skeletal fossils also causes problems of facies and provinciality, yet it can identify an unambiguous signal of the Cambrian explosion, a very significant biotic event with which to define the base of the Phanerozoic.

5. Conclusions

1. The bottom-up reductionism of the ICS Phanerozoic chronostratigraphy has reduced the information of that chronostratigraphic classification. Series, systems, erathems, and eonothems are conceptually more than just collections of stages. They are characterized by significant natural events that can be used to define their bases.
2. A single set of standard global stages is an unworkable abstraction that should be abandoned.
3. Stratigraphers should return to a top-down chronostratigraphy that defines chronostratigraphic units larger than stages by significant natural events that can be correlated globally.

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