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SPOTLIGHT

THE GEOZOIC SUPEREON

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Geological time units are the *lingua franca* of earth sciences: they are a terminological convenience, a vernacular of any geological conversation, and a prerequisite of geo-scientific writing found throughout in earth science dictionaries and textbooks. Time units include terms formalized by stratigraphic committees as well as informal constructs erected *ad hoc* to communicate more efficiently. With these time terms we partition Earth's history into utilitarian and intuitively understandable time segments that vary in length over seven orders of magnitude: from the 225-year-long Anthropocene (Crutzen and Stoermer, 2000) to the ~4-billion-year-long Precambrian (e.g., Hicks, 1885; Ball, 1906; formalized by De Villiers, 1969).

Given the importance of such chronostratigraphic units (*sensu* Zalesiewicz et al., 2004), it is surprising that the key event in the Earth's history, the first appearance of life, is not recognized as a major time boundary. This omission may reflect the relative youth of the field of Precambrian paleobiology. The earliest definitive reports of pre-Ediacaran fossils date to the 1950s (Tyler and Barghoorn, 1954), and only in the last few decades have details of life's early history begun to emerge (e.g., Schopf, 2001; Knoll, 2004). This recent progress in the understanding of early life sets a foundation for augmenting the geologically-derived time units used for the Earth's early history with biological ones, which have already proven so effective when organizing the chronology of the more recent geological past.

In recognition of the importance of life in the Earth's history and the efficiency offered by chronostratigraphic terms, we propose to divide the geological time scale into two informal supereons: Pregeozoic (the abiotic supereon) and Geozoic (the biotic supereon).

Participants of the working group "Phanerozoic body size trends in time and space: Macroevolution and macroecology" during a meeting at NESCent (National Evolutionary Synthesis Center) in Durham, North Carolina, USA. Back row, from left to right: Carl Simpson, Jim Brown, Felisa Smith, Craig McClain, Jon Payne, Seth Finnegan. Front row standing, from left to right: Kate Lyons, Alison Boyer, Jen Stempien, Phil Novack-Gottshall, Steve Wang, Rich Krause. Foreground, from left to right: Dan McShea, Michał Kowalewski. Coauthors, not shown on the photo, include John Alroy, Paula Spaeth, and Shuhai Xiao. Our group has focused on large-scale trends in the fossil record of body size of all organisms, including prokaryotic life. To this end, we have embarked on multiple projects, some of which encompassed the entire known fossil record. Starting with our first meeting, we have struggled unsuccessfully to find time terms that would adequately and efficiently convey the temporal scale of our research. Gradually, it dawned on us: despite the awesome wealth of time terms, from the Archean to the Zanclean, we are missing the most important ones. We lack terms to refer to that most fundamental time boundary that divides Earth's history into its prebiotic and biotic parts. Thus, the Geozoic was born.

DEFINITION OF THE GEOZOIC

The Geozoic denotes the time of life's existence on our planet. Its lower and upper boundaries are defined by the first and last appearance of life, respectively. The upper boundary cannot be defined until life has gone extinct on our planet. However, ample precedent exists for open-ended boundaries. For example, the Cenozoic and the Quaternary are formal units that potentially (and continually) transcend the present. Yet, their top boundaries are set at 0 yrs on geological time scales, which is not only permissible, but also conservative. The end point of the Geozoic can be only younger than today: life is still unequivocally present on Earth.

The lower boundary is uncertain due to controversies surrounding the earliest records of life. Molecular clock analysis places the divergence between archaebacteria and the archaebacterial genes in eukaryotes at 3.97 ± 0.32 Ga (Hedges et al., 2001), but such estimates are not without problems. The oldest proposed direct geological evidence for life comes from geochemical signatures in ca. 3.8 Ga rocks

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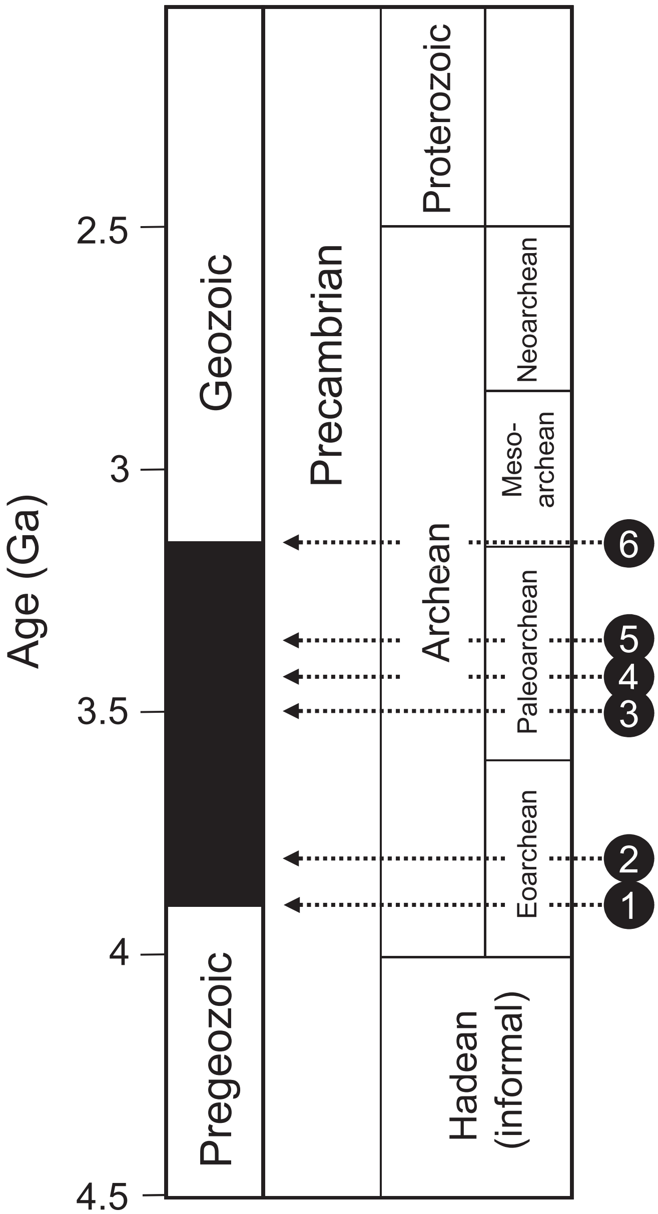

FIGURE 1—Graphic illustration of bio-chronological uncertainties (a black bar at 3.8–3.2 Ga) surrounding the oldest fossils (i.e., the oldest geological evidence for presence of life on our planet). The numbers in circles refer to a selection of proposed geological evidence for earliest life: 1) $\delta^{13}C$ of graphite inclusions from 3.8 Ga rocks in Akilia (Mojzsis et al., 1996; but see van Zuilen et al., 2002); 2) $\delta^{13}C$ of graphite globules in >3.7 Ga turbiditic and pelagic sedimentary rocks from the Isua supracrustal belt in west Greenland (Rosing, 1999); 3) $\delta^{13}C$ of carbonaceous material and filamentous structures from the ca. 3.5 Ga Dresser Formation in Western Australia (Ueno et al., 2001, 2004); 4) the ca. 3.46 Ga Apex Chert microfossils in Western Australia (Schopf, 1993; but see Brasier et al., 2002); 5) stromatolites from the ca. 3.45 Ga Strelley Pool Formation in Western Australia (Allwood et al., 2006, 2009); 6) filaments from 3.2 Ga sulfide deposits in Western Australia (Rasmussen, 2000).

(Mojzsis et al., 1996), and the oldest reported microfossils are ca. 3.5 Ga (Schopf, 2006). However, these data are also controversial (Brasier et al., 2002; van Zuilen et al., 2002; Fedo et al., 2006) and hampered by dating uncertainties. Nonetheless, there is widely-accepted evidence for the presence of stromatolites by 3.45 Ga (Allwood et al., 2006, 2009) and microfossils by 3.235 Ga (Rasmussen, 2000). Thus, a reasonable estimate of the Geozoic's lower boundary is somewhere between ca. 3.8 and ca. 3.2 Ga. The maximum age uncertainty of the boundary is ~0.6 billion years (Fig. 1), comparable to the duration of the Phanerozoic Eon. Of course, no chronostratigraphic boundary is error free, and time uncertainties increase with geologic age (e.g., Gradstein et al., 2004,; Figs. 1.5–1.6). Due to scarcity of unquestionable biostratigraphic data in the Archean, placing confidence intervals (e.g., Strauss and Sadler, 1989; Marshall, 1997) on the stratigraphic range of life is currently unfeasible.

The Geozoic can be used as either an abstract (technical) or a practical concept. Technically, it represents the actual temporal range of life's existence on Earth. In practice, it is defined by the oldest geological record of life currently known. And because the origin of life predates its oldest fossil record, the practical Geozoic represents the most conservative estimate of the biosphere's existence time. In its strictest sense, the term Geozoic implies that life must have existed continuously since its origin: no total extinctions and re-originations have occurred. Note that monophyly is not an issue here: if life were discovered to be polyphyletic, at any point in its history, the Geozoic would be unaffected; all that is required is continuity. Regardless of the exact boundary placement, the Geozoic encompasses multiple eons (i.e., the Phanerozoic, the Proterozoic, and most of the Archean) and merits a chronostratigraphic rank of informal supereon. The time from the formation of Earth until the oldest direct evidence of life (i.e., the Hadean and the early Archean) can be referred to as Pregeozoic, thus dividing the earth's history into two supereons (Figs. 1–2).

The proposed supereons are not intended to supersede the existing large-scale time units that subdivide the history of Earth into times of macroscopic (Phanerozoic) and dominantly microscopic (Precambrian) life. Rather, they aim to codify our vocabulary by acknowledging the most important event in the history of life.

ETYMOLOGY AND ALTERNATIVE TERMINOLOGY

The term Geozoic denotes the time of life on Earth (Geo = Earth and zoic = life). To be semantically precise, -zoic denotes animal life. However, in geological terminology, the suffix -zoic is used more broadly to denote any life. Thus, textbooks and dictionaries translate Phanerozoic as the time of visible, obvious, evident, or well displayed life (e.g., Whitten and Brooks, 1978; Stanley, 2009), and not the time of visible animal life. The largely abandoned term Cryptozoic is defined as the time of hidden or obscure life (e.g., Prothero and Dott, 2010), and not obscure animal life. Although some of the -zoic terms were originally proposed to denote animals, usage of the suffix has evolved to denote all life.

Following our conference presentation on the Geozoic (Kowalewski et al., 2009), multiple colleagues inquired why we had not considered the term Biozoic. This term is problematic. First, the suffix -zoic is used by geologists to denote all life, which makes Biozoic redundant. Also, the prefix bio, could be misread as an emphasis of the strict meaning of the word Zoic, equating Biozoic with the time of animal life. Finally, Biozoic does not make any reference to earth, which makes it vague from the geocentric perspective of stratigraphy (Zalasiewicz et al., 2004). For example, if conclusive evidence of Pregeozoic life is found on Mars, the lower boundary of the Geozoic would not be affected, but a case could be made for redefining the Biozoic. Others suggested the term Zoic, but this term also does not make any reference to earth and may be more appropriate for denoting the time of life in the universe. The term Gaiazoic was also proposed, but this is a politically charged term that we chose to avoid.

The term Pregeozoic is derived based on the same logic that had been used to coin the term Precambrian (but see Martinsson, 1973). Pregeozoic is synonymous with Azoic (Martinsson, 1973; see also Goldblatt et al. [2009] for discussion of pre-Archean, non-biotic time units). The term Azoic does not make any reference to Earth and could serve as a counterpart to the term Zoic to denote the prebiotic history of the Universe. Admittedly, the terms Zoic and Azoic sound like

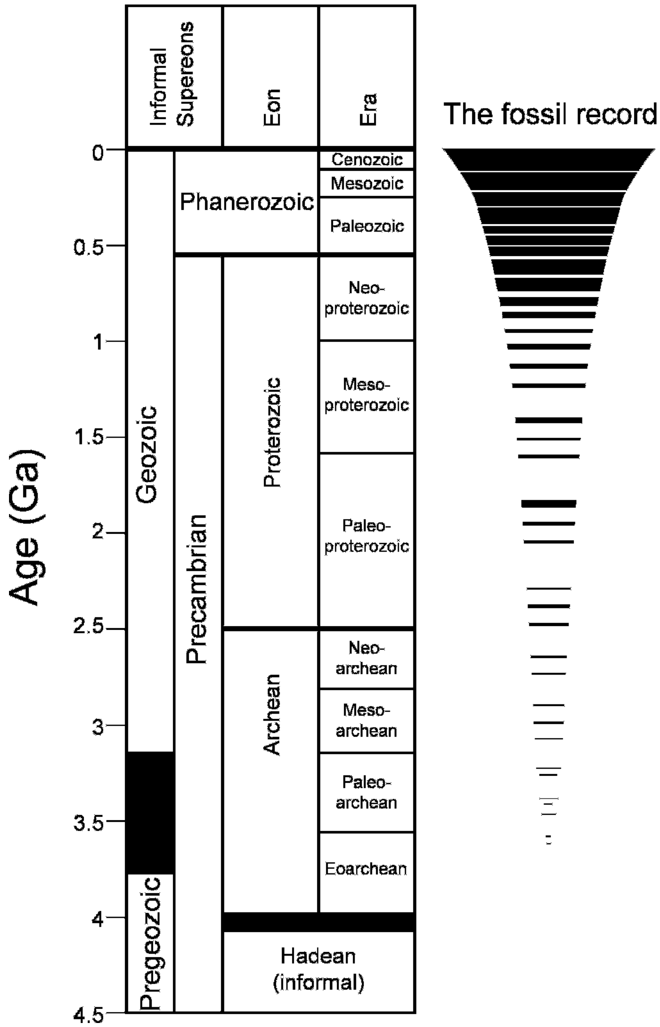

FIGURE 2—A schematic geological time scale summarizing the temporal relation between the two informal supereons proposed here (Geozoic and Pregeozoic) and the major informal (supereons) and formal (eons, eras) geochronological units used widely in geosciences. Following the dual literature usage, the term Phanerozoic is shown both as an eon and as a supereon. Thick zone at the Pregeozoic-Geozoic boundary represents the current uncertainty in our knowledge of what constitutes the oldest, unquestionable evidence for the presence of life on our planet.

names of evil characters from a low budget sci-fi movie and may thus be not mundane enough to be acceptable as chronostratigraphic terms.

Online searches (Georef, ISI Web of Knowledge, and Google Scholar; 11/30/2009) suggest that the term Geozoic has not been used in the geoscience literature. Our recent abstract (Kowalewski et al., 2009) is the only relevant occurrence of the term. A Google search (11/30/2009) yielded 57 hits for the Geozoic. Except for those pertaining to our abstract, these entries represented blogger names, e-Bay postings, and other obscure hits, including a Trojan virus that delayed somewhat the preparation of the manuscript.

PRACTICAL JUSTIFICATIONS

Successful terms are invented because they are needed for a specific reason and then propagate because they prove useful beyond their original need. The term Geozoic was invented because the NESCent Body Size Working Group (2006–2009) needed a simple term to refer to the entire fossil record (as in "the Geozoic history of body size"). With that need came a realization that such a term would be useful, for multiple reasons, to many researchers who study the bulk or the entirety of life's history.

1. A purely pragmatic reason for introducing new terminology is linguistic parsimony. Terms save words and characters, allowing for shorter titles and succinct abstracts. Brevity is not just desirable, but often required: many journals set stringent limits on the length of titles, abstracts, or text. The published literature offers many cases that illustrate potential utility of the term Geozoic. For example: "…little evolution at the macroscopic level took place for over half of the entire history of life on Earth" (Schulze-Makuch and Irwin, 2004, p. 39) could be "…little evolution at the macroscopic level took place for over half of the Geozoic;" "We would argue that it is simplistic to expect only one pattern of stability in the entire fossil record" (Tang and Bottjer, 1997, p. 475) could be "We would argue that it is simplistic to expect only one pattern of stability in the Geozoic"; and "…together comprise <20% of the total duration of life on Earth" (Payne et al., 2009, p. 24) could be "…together comprise <20% of the Geozoic." The time terms are particularly useful in titles, which are often more effective when brief. For example, the title: "Biotic enhancement of weathering and surface temperatures on earth since the origin of life" (Schwartzman and Volk, 1991, p. 357) could be shortened as "Biotic enhancement of weathering and surface temperatures in the Geozoic."

2. The need for Geozoic is illustrated by inadequacy of existing terms, often used due to lack of appropriate terminology. An ISI Web of Knowledge search (12/02/2009) for the subject="Phanerozoic" revealed that the journal *Precambrian Research* published 119 papers apparently focused on post-Precambrian times (only four journals published more papers on the Phanerozoic). Very likely, those papers dealt with both the Precambrian and Phanerozoic, but lacked a single subject tag to denote such a long time interval. The Geozoic tag could allow one to highlight papers (whether published in *Precambrian Research* or elsewhere) that deal with both the Precambrian and the Phanerozoic. Use of the term could also place greater emphasis on the origin of life as a critical temporal event. The term would likely work even for studies that do not pertain to the entirety of the Geozoic. Chronostratigraphic terms are used often to denote major portions or select segments of a given time interval. For example, authors find it convenient to use Phanerozoic when analyzing its select parts (e.g., Powell and Kowalewski, 2002; Riding, 2002) or Cenozoic when primarily focusing on the Neogene (e.g., Funk et al., 2009).

3. Temporal units are indispensable indexing tags for identifying publications that deal with specific time intervals or target temporal scales of a given magnitude. Anyone interested in large-scale patterns in the evolution of multicellular life can use the Phanerozoic tag to find many relevant publications, while those interested in recent changes in ecological communities can use the Holocene tag to assemble their initial bibliography. Why then, having such efficient terms for biologically relevant time scales and time intervals, do we lack the most important tag? We have a special name for the time of old life on Earth (Paleozoic). We have a name for the time of obvious life on Earth (Phanerozoic). However, absurdly, we lack a name for the time of life on Earth (Geozoic).

4. The Geozoic-Pregeozoic terminology could also facilitate a more transparent organization of introductory geological textbooks. Currently, textbooks are organized lucidly for the Phanerozoic part of the Earth's history, often having time-parallel sections on biological and geological processes (e.g., Paleozoic Life and Paleozoic Earth), but their Precambrian parts are less intuitive chronologically. In particular, the text dedicated to the origin of life and earliest life is often buried in chapters that deal with the whole Archean or even Archean and Hadean. This problem relates to the lack of explicit separation of the prebiotic and biotic Earth. The Geozoic offers a convenient tool for presenting the Precambrian history of life in a more structured manner in textbooks and in classrooms.

5. Finally, the term Geozoic may become increasingly useful as the perspective of evolutionary research continues to expand, especially with the discovery of water-bearing worlds in our own Solar System

(e.g., Lunine et al., 2003; Clark, 2009) and the arrival of new technology for detecting Earth-scale planets elsewhere in our galaxy (e.g., Gaidos et al., 2007). The notion that life exists on other planets, and that it might be accessible to scientific inquiry, has gained scientific credibility, culminating in the creation of the field of exobiology. It is thus possible that in the not-too-distant future we will come to think of the history of life on Earth comparatively, that we will start discussing origins, durations, and trajectories of evolution on life-bearing planets generally, not just on Earth. We may become interested in the frequency of certain kinds of events affecting life over its various histories or the differences in the sorts of evolutionary trends occurring on different planets. When we do so, we will need a convenient way to refer to the relevant time period on Earth as well as corresponding terms for other worlds. It may be too soon to develop a full vocabulary for making these comparisons. But it is not too soon to recognize, in our use of language, that our thinking has expanded to encompass a larger context: all of life, including its whole duration on Earth, the Geozoic.

Note that the Geozoic will be validated if future users find any of the above arguments compelling. Some may agree that the Geozoic offers a useful tag, but dismiss the linguistic parsimony argument. Others may find it useful for structuring syllabi, but scorn the idea of extraterrestrial terms. Even we do not support all the above arguments with equal enthusiasm, but all of us find at least some of those points compelling enough to campaign for the Geozoic.

One may raise objection that new terms such as Geozoic cannot be used without explaining what they mean, which defeats the idea that they would become useful. Using this type of logic, it would be impossible to ever invent a new term. Of course, you will need an explanation at first: this is true for all new terminology. But presumably, as the term becomes more known over time, the need for an explanation will go away. Moreover, if anything, Geozoic is more self-explanatory than existing terms. If you asked someone what the Geozoic refers to, he or she might be able to figure it out etymologically without knowing the definition. But there's no way someone could figure out precisely what the Mesozoic refers to without an explanation.

Another objection may be the issue of the vagueness of the lower boundary of the Geozoic. Again, this would be true for all time intervals, and if this argument had been taken seriously in the past we would not have been able to name any time units at all. At least for the Geozoic, the time encompassed is conceptually clear, even if the lower boundary is imprecisely estimated.

Finally, an understandable reaction would be to ask why use the term if one can simply say "time span of life on Earth." We are certain that similar criticisms must have been voiced when successful terms such as Phanerozoic were first introduced. And the creation of a new technical term does not preclude the use of such longer, and perhaps more poetic, turns of phrase.

FINAL REMARKS

The terms Geozoic and Pregeozoic offer an expedient way to denote geological processes, patterns, and records that took place before (Pregeozoic) and after (Geozoic) the origin of life. This convenience is the only valid reason for proposing new terminology and its only justification.

It is impossible to predict if or when the terms proposed here will become used widely enough to validate them. New terminologies are authorized by users, and informal geological time units tend to suffer from substantial time inertia. For example, geoscientists started to use the term Phanerozoic more widely only in the 1970s, even though the term was introduced 40 years earlier (Chadwick, 1930). However, in this era of Google Scholar, indexed databases, and scientific blogs, short all-encompassing terms such as Geozoic may prove fittest linguistically—fast in dispersal and resistant to terminological extinctions.

"In the world of components there are no equivalents," noted Erofeev (1994, p. 68), when discussing substitute alcoholic drinks that Russians enjoyed during the Soviet Era. We believe that this dictum applies to the Geozoic; a supereon that denotes the entire documented history of life on our planet with just one seven-letter word. None of the currently used time units offers comparable terminological expedience. None recognizes the historical importance of life as concisely.

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