TOWARDS A “NATURAL TIMESCALE” FOR 88 PERCENT OF EARTH HISTORY

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Abstract

The timescale for the Precambrian is marred by many fundamental problems, not in the least that the final recommendations of the now dissolved Precambrian timescale committee were inadequately circulated (a one-page letter in Geolog!). Hence, what is the "Eoarchean"? Or for that matter, the only marginally better known "Paleoarchean"? Evidently, the current subdivisions have been only partially accepted by practicing Precambrian stratigraphers and "early Earth" researchers. With every new planetary mission it becomes more obvious that there is a strong need to view the history of the Earth in its natural context, i.e. the evolution of the inner solar system. The late heavy bombardment could allow for synchronization between terrestrial, lunar, and other planetary timescales and a formal definition of Preston Cloud's Hadean (who needs the "Priscoan" of Harland et al. (1982)?). With the discovery of ca. 4.4 Ga detrital zircons and a number of high-resolution chronometers that can address events during planetary formation, there may be a need to introduce yet other eons to provide a vocabulary for the rapidly evolving knowledge about Earth's first 100 million years. At younger times, where Earth's history is better chronicled in a more extensively preserved stratigraphic record, we must return to the "golden spike" concept and define first-order boundaries in the history of the Earth in terms of events recorded in the rock record, rather than arbitrary, absolute, age boundaries.

Introduction

The geological timescale and its evolution (Fig. 1a,b) reflect the growth of the geological sciences over the last 2-3 centuries. On the one hand, the evolving timescale provides the essential nomenclature to classify, analyze, and communicate Earth’s history, while on the other it closely reflects the overall intellectual framework in which Earth history, as recorded in the rock record, is viewed. Only relatively recently, an explosion in knowledge of the Precambrian (88 percent of Earth history!), driven in large part by rapid advances in geochronology, has led to a formal subdivision of the Precambrian (Fig. 2).

Contrary to historical practice, and against the specific critique of many leading scholars in the field (e.g. Cloud, 1987; Crook, 1989; Nisbet, 1991), the Subcommission on Precambrian Stratigraphy of the International Union of the Geological Sciences (Plumb and James, 1986; Plumb, 1991) chose a sterile, purely numerical, basis of absolute ages for subdividing Precambrian time, resulting in a timescale for much of Earth history that is “convenient” in terms of round numbers, but is fundamentally flawed and divorced from key events in the stratigraphic record. It is incumbent on the present geological science community to correct this, leading to a timescale that, ideally, 1) is defined in terms of the extant rock record; 2) highlights and focuses attention on key events in Earth history; 3) for the early Earth highlights events that may be common among planetary bodies in the inner solar system; and 4) provides a useful nomenclature of sufficient resolution to allow meaningful communication of 88 percent of Earth history.

Flaws of the present Precambrian timescale

Significant flaws of the present Precambrian timescale are:

- Subdivisions are defined in terms of defined, precise, age numbers (e.g., 2500 Ma for the Archean-Proterozoic boundary) rather than in terms of specific “events” observable in the only primary record of Earth’s secular evolution, the extant rock record (e.g., Cloud, 1987; Nisbet, 1991).
- Boundaries were chosen in perceived gaps in the stratigraphic record and thus are based on negative evidence.
- Even in existing sections with sufficient datable horizons, a precise absolute age (e.g., 2500 Ma) cannot be located due to the inherent uncertainty in decay constants (Ludwig, 2000; Begemann et al., 2001) of even the most precise chronometers (e.g., a conservative estimate for the inherent uncertainties of the U-Pb system at ca. 2500 Ma are in the order of ±10 million years, relative to an externally defined absolute age, or another chronometer; see Figs. 3, 4).
- The proposed timescale for the Archean was inadequately published (e.g., Lumbers and Card, 1991), resulting in formal and proposed subdivisions (e.g., Neoachean, Fig. 2) that are either not being used or used inconsistently in the literature on the Precambrian.
- Subdivision names were chosen so as to avoid reference to particular sections (Plumb and James, 1986). This further contributes to poor recognition and acceptance (e.g., what is the Calymmian Period, or the Eoarchean Era? see Fig. 2).
- In its present form, the timescale is heterogeneous, being based on biostratigraphy, extinctions, and other key events in the Phanerozoic, and fixed, defined, ages in the Precambrian. For instance, the youngest subdivision of the Proterozoic (“Neoproterozoic III”, see Fig. 2) has a defined, numeric, lower boundary of 650 Ma, whereas its upper boundary is defined bio- and chronostratigraphically in terms of the base of the overlying Cambrian, i.e. the onset of “Cambrian radiation” of diverse and plentiful shelly metazoan fossils dated at ca. 544 Ma (e.g., Bowring et al., 1993).
- And perhaps somewhat more esoteric, the “year” is a non-SI unit, and in astronomical terms a variable. Hence, what is the relevance of the present “standard year” to Archean orbital dynamics (e.g., Trendall, 1991).

Perhaps the only positive (?) outcome of the proposed Precambrian timescale (Fig. 2) has been that it has stabilized, at least temporarily but artificially, the debate on the age and significance of the Archean-Proterozoic boundary. This has facilitated, somewhat, the recent literature on the late Archean, but at the expense of clear logic and procedure (see above) and the now well-established realization that the Archean-Proterozoic “boundary” is a transition in tectonic styles that is fundamentally diachronous and in some cratons happened as early as 3.1 Ga, whereas in others it took place as late as 2.5-2.4 Ga (e.g., Windley, 1984; Blake and Groves, 1987; Cloud, 1987; Nisbet, 1991; Bleeker, 2003).

A better timescale

As pointed out repeatedly by several leading scholars of Precambrian geology, a global timescale should be based on the only primary record of Earth’s secular evolution that we have: the extant, although fragmentary, stratigraphic record. Subdividing time in the absence of a physical standard (i.e., in geology: the stratigraphic record) is meaningless (Cloud, 1987).

Boundaries should be placed at “key events” in the stratigraphic record to establish a “natural timescale” for the evolution of planet Earth. Ideally, these “key events” can be observed globally, but at a minimum should be significant in one well-preserved section (e.g., for the Archean-Proterozoic boundary the onset of giant iron formations in the succession of the Mount Bruce Supergroup, Hamersley Basin, Western Australia? Or perhaps the intrusion of the Great Dyke, now precisely dated at 2575 Ma and indicating the brittle fracturing of the Archean Zimbabwe craton?). This is the “golden spike” approach that is widely accepted for the Phanerozoic and should be equally adopted for Precambrian. This would lead to a nomenclature of natural subdivisions and corresponding names that would be meaningful to those researchers working on a particular interval of Earth’s history.

The onset of the Archean could be easily defined in terms of the first preserved supracrustal rocks in the geological record, a distinction currently held by ca. 3850 Ma rocks of the Isua greenstone belt of SW Greenland.

For the early Earth, key events could be based on either biochemical or isotopic characteristics that track the evolution of life on Earth (e.g., Nisbet and Sleep, 2001), an approach that would be a natural extension of the methodologies in the Phanerozoic. If life was seeded from elsewhere in the solar system (e.g., Mars?, asteroids or comets?), this would ultimately allow for synchronization, at some key chronostratigraphic horizon, of the terrestrial and Martian timescales. Alternatively, major impact events (e.g., the late heavy bombardment) may provide such natural synchronization between different planetary timescales, including that of our Moon.

The emerging geological record prior to the first supracrustal rocks should be referred to as belonging to the Hadean Eon (Cloud, 1972), in recognition of the significant contributions made by Preston Cloud and simply because it has priority over Harland’s Priscoan (Harland et al., 1982).

And finally, with the initial formation of the Earth-Moon system coming slowly into focus, it may prove useful to have a pre-Hadean eon, and subdivisions, that would facilitate discussions of this early stage in planetary evolution, but admittedly this is a long shot at present.

Conclusions

The main point of this essay is to re-emphasize that the current numeric basis for the Precambrian timescale is fundamentally flawed and that there are excellent candidates for an event-based “natural timescale” for 88 percent of Earth’s history. A selection of “key events” to mark first-order boundaries would stimulate the Precambrian community to attempt correlation of such event-based boundaries world-wide, while at the same time it would result in a new wave of focused geochronological research to provide accurate and precise timing information for these boundaries. A similar stimulus is evident in research on many of the first-order timescale boundaries in the Phanerozoic (e.g., Bowring et al., 1993, 1998), both in terms of timing (e.g., efforts to precisely date the base of the Cambrian, the Permo-Triassic boundary, or the K-T boundary), and in terms of testing the validity of various processes responsible for these boundaries in the light of specific timing scenarios (e.g., gradual (volcanism) or catastrophic (bolide impact) extinction of the dinosaurs). Applying the same rigour to the Precambrian would result, undoubtedly, to significant advances in our understanding of Precambrian evolution, and ultimately in a valid “natural” timescale for planet Earth.

Acknowledgements

I discussed some of the ideas expressed above with Euan Nisbet, who together with Preston Cloud has been a vocal critic of the present Precambrian timescale procedure. Discussions with Yuri Amelin and Richard Stern helped clarify the magnitude of the limitations due to decay constant uncertainties.

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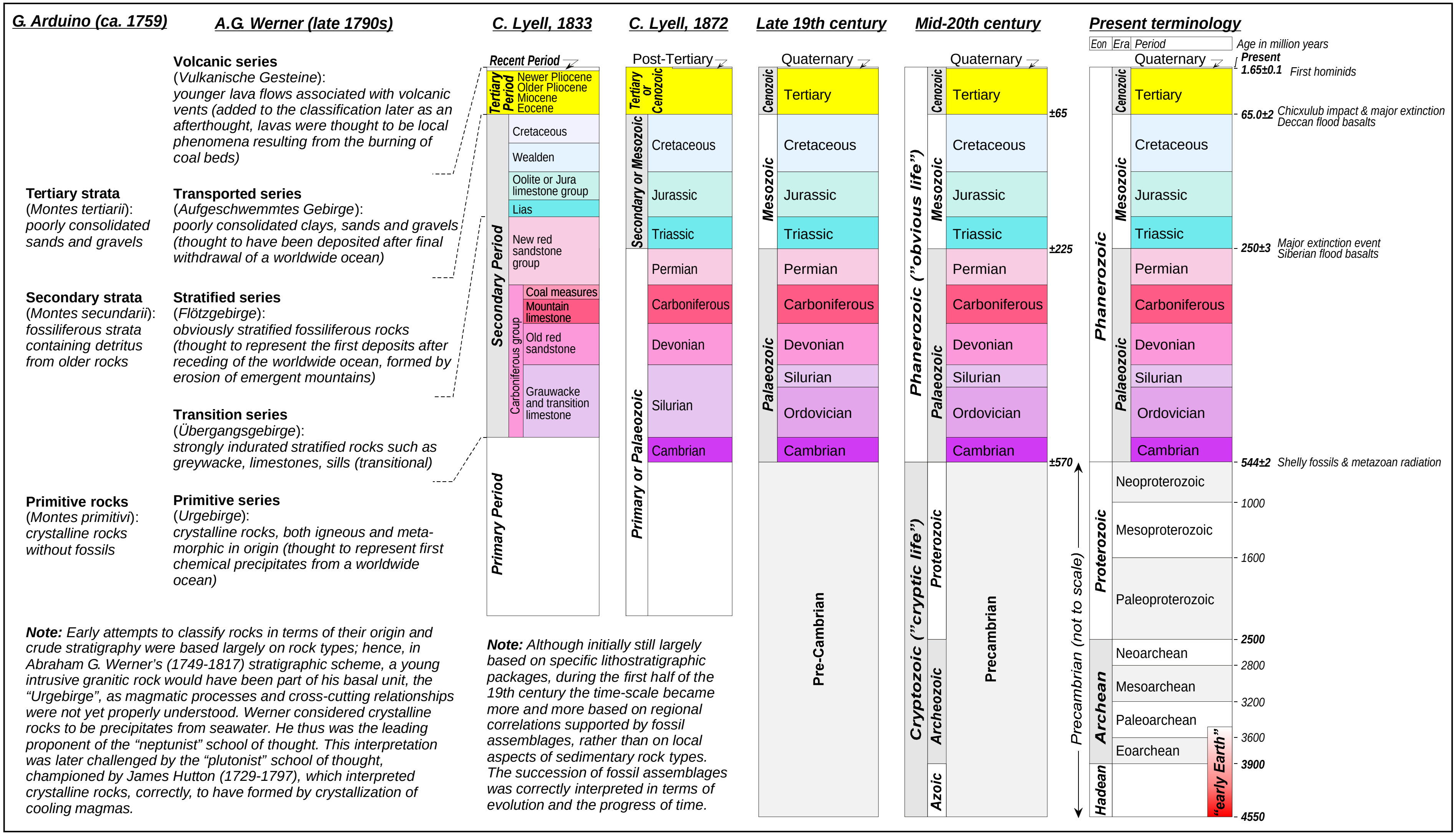
Figure captions

Figure 1: a) Historical development of the geological time-scale. b) Present time-scale, including formal and proposed subdivisions of the Precambrian; full column on the right is to scale and is annotated with key events in Earth's evolution. The interval highlighted "early Earth" is a commonly used informal designation for Earth's first Gigayear, from the time of accretion to ca. 3.5 Ga. Exponentially decreasing impact intensity (red curve) is schematic only and includes the assumption of a discrete "late heavy bombardment" episode.

Figure 2: Subdivision of the Precambrian time-scale (after Plumb, 1991; and Lumbers and Card, 1991). Boundaries are defined chronometrically in terms of absolute ages, and were chosen to coincide with perceived gaps in the global stratigraphic record.

Figure 3: Graphical representation of the magnitude of decay constant uncertainties in the U-Pb system (±0.11% for ^{238}U, and 0.14% for ^{235}U, respectively; see Ludwig (2000) and references therein). Concordia diagrams are shown at a) ca. 2.5 Ga and b) 4.0 Ga, each with three hypothetical zircon analyses of different precision: 1% errors (pink), for a typical SHRIMP analysis; 0.2% errors (red) for a typical ID-TIMS analysis; and 0.01% (small black ellipse coincident with the center of the other two ellipses) to simulate a geologically and analytically perfect zircon age. Numbers in square brackets are decay constant-related uncertainties in the weighted ^{207}Pb/^{206}Pb age calculated by Ludwig's (2000) formal error propagation. These are reflected graphically by the width of the "intecept" between the regression line and the "concordia band". Note that at ca. 2.5 Ga this uncertainty is ±6.5 Ma. More conservative decay constant uncertainties (times 1.5) would lead to a fundamental age uncertainty of ±10 Ma.

Figure 4: Hypothetical stratigraphic section at or near the numerically defined Archean-Proterozoic boundary. Note that the timing of an important stratigraphic feature(indicated by arrow), even when bracketed by precisely dated tuff layers, remains uncertain relative to an externally defined absolute age (e.g., 2500 Ma). The uncertainty range (arrows) is shown at ±6.5 Ma level, but could be as high as ±10 Ma.



Volcanic series
(*Vulkanische Gesteine*):
younger lava flows associated with volcanic vents (added to the classification later as an afterthought, lavas were thought to be local phenomena resulting from the burning of coal beds)

Tertiary strata
(*Montes tertiarii*):
poorly consolidated sands and gravels

Transported series
(*Aufgeschwemmtes Gebirge*):
poorly consolidated clays, sands and gravels (thought to have been deposited after final withdrawal of a worldwide ocean)

Secondary strata
(*Montes secundarii*):
fossiliferous strata containing detritus from older rocks

Stratified series
(*Flötzgebirge*):
obviously stratified fossiliferous rocks (thought to represent the first deposits after receding of the worldwide ocean, formed by erosion of emergent mountains)

Transition series
(*Übergangsgebirge*):
strongly indurated stratified rocks such as greywacke, limestones, sills (transitional)

Primitive rocks
(*Montes primitivi*):
crystalline rocks without fossils

Primitive series
(*Urgebirge*):
crystalline rocks, both igneous and meta-morphic in origin (thought to represent first chemical precipitates from a worldwide ocean)

Note: *Early attempts to classify rocks in terms of their origin and crude stratigraphy were based largely on rock types; hence, in Abraham G. Werner's (1749-1817) stratigraphic scheme, a young intrusive granitic rock would have been part of his basal unit, the "Urgebirge", as magmatic processes and cross-cutting relationships were not yet properly understood. Werner considered crystalline rocks to be precipitates from seawater. He thus was the leading proponent of the "neptunist" school of thought. This interpretation was later challenged by the "plutonist" school of thought, championed by James Hutton (1729-1797), which interpreted crystalline rocks, correctly, to have formed by crystallization of cooling magmas.*

Note: *Although initially still largely based on specific lithostratigraphic packages, during the first half of the 19th century the time-scale became more and more based on regional correlations supported by fossil assemblages, rather than on local aspects of sedimentary rock types. The succession of fossil assemblages was correctly interpreted in terms of evolution and the progress of time.*

Figure 1a
Bleeker, 2003

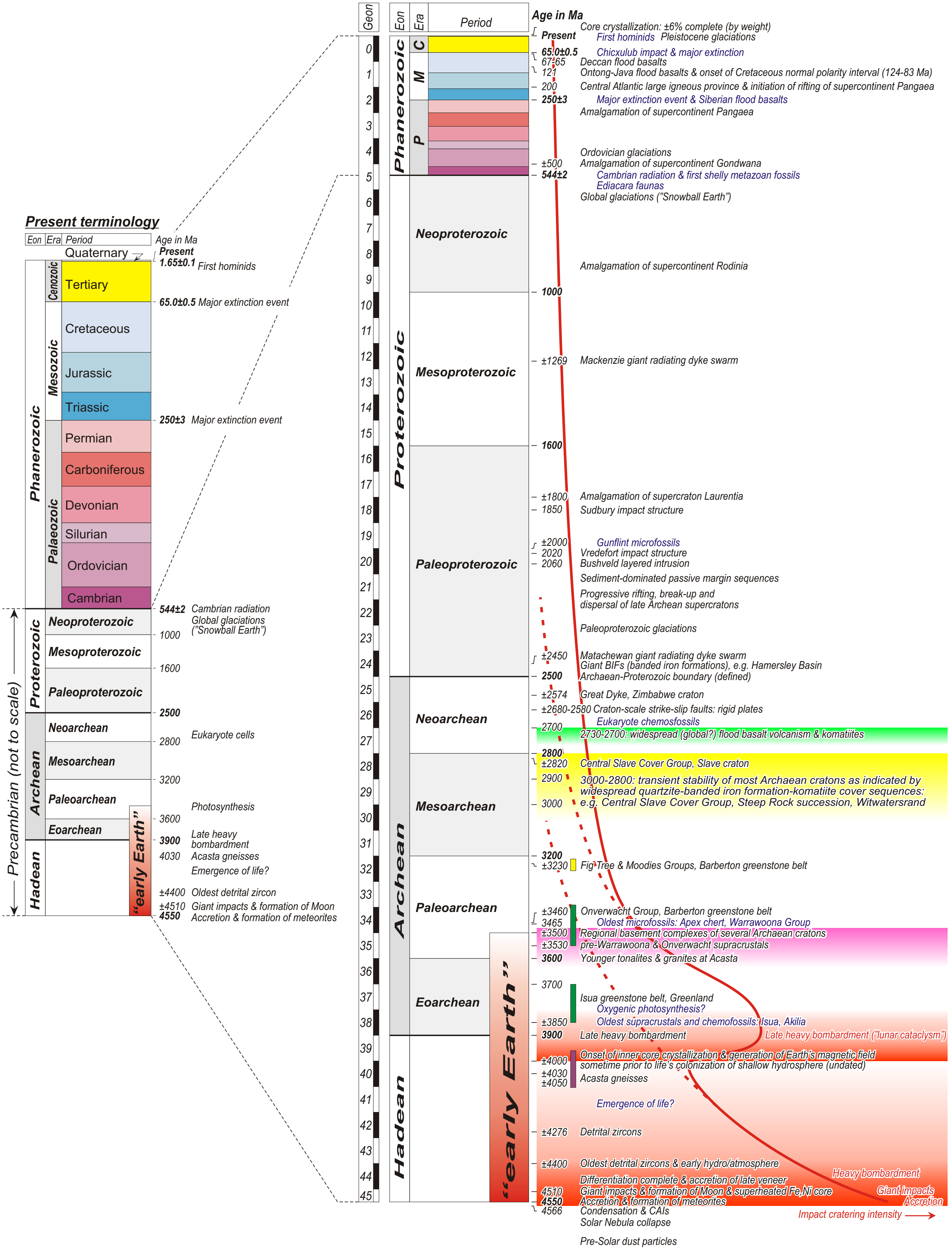


Figure 1b
Bleeker, 2003

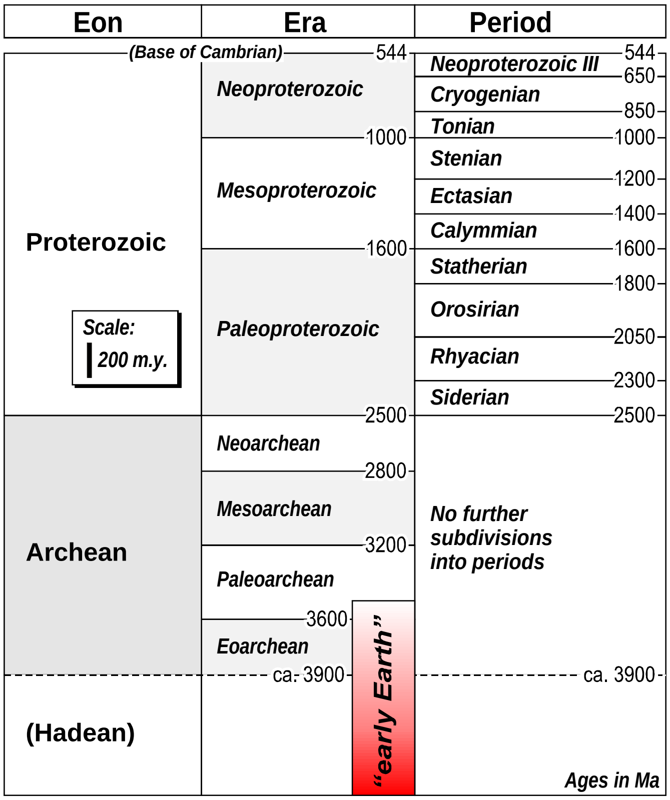


Figure 2
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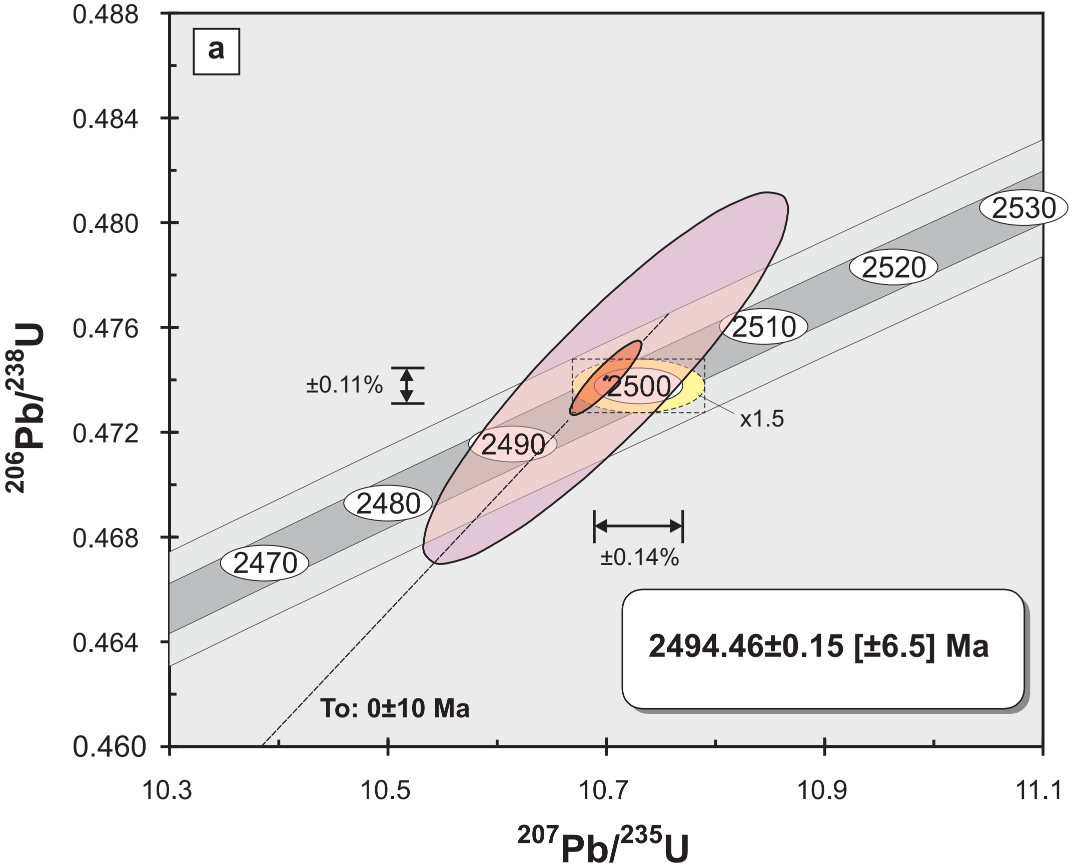

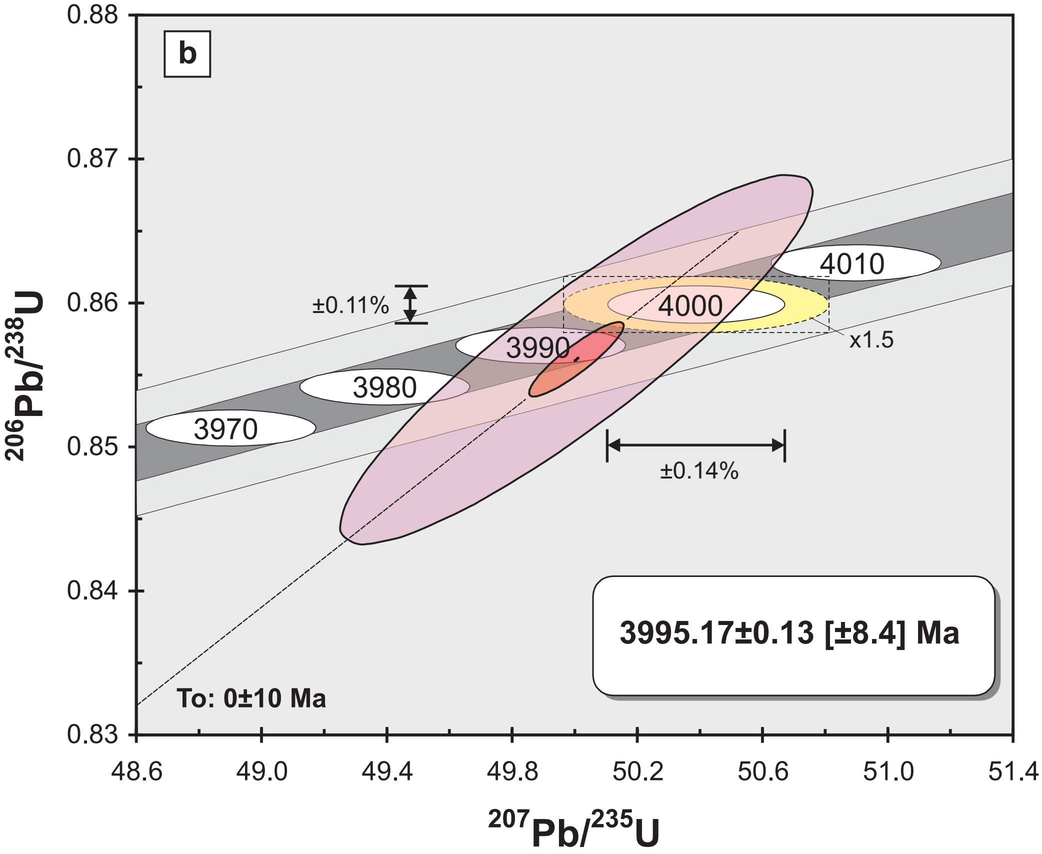

Figure 3
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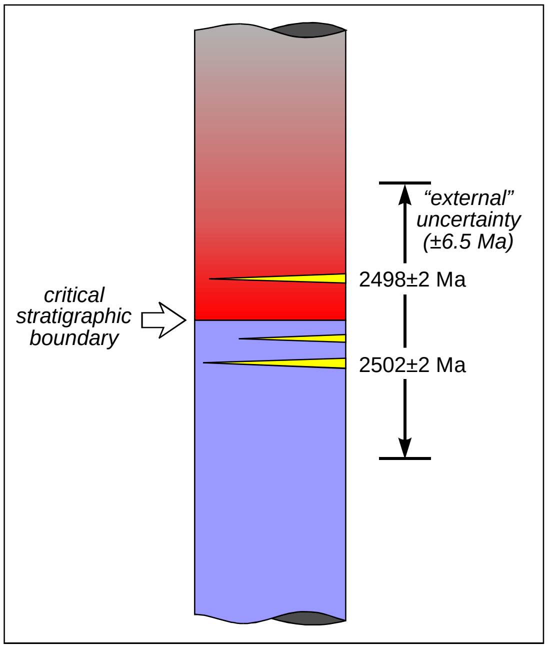

Figure 4
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