Towards a 'natural' time scale for the Precambrian – A proposal

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A proposal is put forward to redefine the geological time scale for the Precambrian. Flaws of the present, chronometrically defined, time scale are discussed and illustrated. It is concluded that we need to go back to the rock record to define a "natural" time scale, in which major divisions (eons, eras, etc.) are defined in terms of first-order events and transitions in the observable stratigraphic record. For the earliest part of Earth history, we need a time scale, including a formalized Hadean eon, that is fully consistent with rapidly evolving insights from planetary science. □ *geological time scale, Precambrian, Proterozoic, Archean, Hadean, rock record.*

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Background

From the time of initial accretion and differentiation (ca. 4567–4560 Ma; e.g. Allègre *et al.* 1995) to the first appearance of abundant hard-bodied fossils (the onset of the Cambrian Period, now dated at 542 Ma; Bowring *et al.* 2003), the Precambrian spans 88 percent of Earth history. Yet, there is no coherent view of a geological time scale to help describe, analyze, calibrate, and communicate the Precambrian evolution of planet Earth.

The *status quo* is a geological time scale for the Precambrian (Fig. 1) that is both incomplete and flawed (e.g. see discussions by Cloud 1987; Crook 1989; Nisbet 1991; Bleeker 2003a), and is defined in terms of arbitrary, strictly chronometric, absolute age boundaries that are divorced from the only primary, objective, record of planetary evolution: the extant rock record.

At a recent conference on the geological time scale and its calibration (NUNA 2003), sponsored by the International Committee on Stratigraphy (ICS), there was broad consensus on the view that this arbitrary, chronometrically defined, Precambrian time scale fails to convey the richness of the Precambrian rock record and therefore impedes scientific understanding of geological processes by diverting attention away from observable first-order stratigraphic boundaries and transitions.

Specific criticisms of the present Precambrian time scale are listed in a short Appendix to this Proposal, but one key point deserves elaboration here: the uncertainty in decay constants of ^{238}U and ^{235}U. These uncertainties (e.g. Ludwig 2000) conspire in such a way that most age dates for the Precambrian (predominantly upper intercept ^{207}Pb/^{206}Pb zircon ages, particularly prior to 1 Ga) have a non-trivial fundamental 'fuzziness' (e.g. about ±6.5 million years at ca. 2500 Ma; Fig. 2). This fundamental uncertainty increases to ±10 million years at ca. 4000 Ma. Definition of boundaries in terms of arbitrary, round, absolute ages, although superficially appealing, is therefore naïve. Correlation of such boundaries between distant sections, on the basis of even our best geochronometer (U-Pb ages on single zircons), can be no better than 5–10 million years (in terms of absolute ages), even if all other sources of uncertainty (e.g. analytical scatter, Pb loss, or cryptic inheritance) are negligible. In principle, this fundamental uncertainty could be reduced by defining boundaries explicitly in terms of ^{207}Pb/^{206}Pb zircon ages or isotopic ratios, rather than absolute age numbers, but this would make any time scale even less transparent. Furthermore, it would not solve the problem of intercalibration between different chronometers.

Clearly, there can be only one conclusion: the Precambrian time scale should be (re)defined in terms of the only objective physical standard we have, the extant rock record. Boundaries should be placed at key events or transitions in the stratigraphic record, to highlight important milestones in the evolution of our planet. This would be analogous to the 'golden spike' approach employed in the Phanerozoic (e.g. see Gradstein *et al.* 2003 for a recent discussion). Various geochronometers (U-Pb; ^{40}Ar-^{39}Ar; Re-Os, etc.), each

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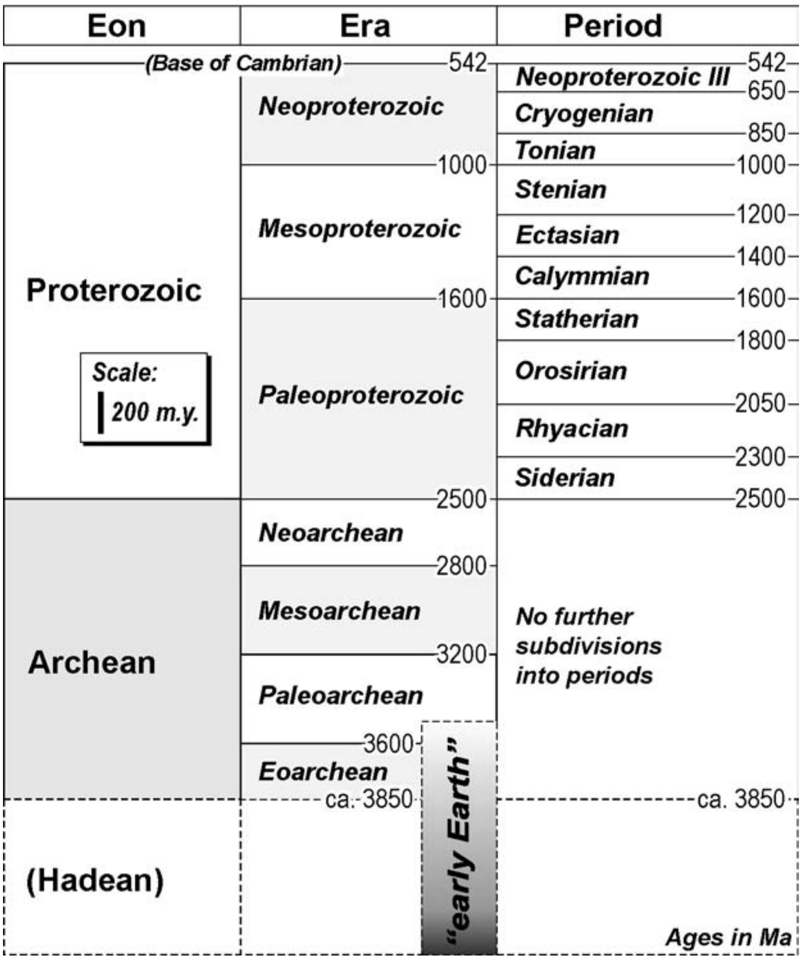

Fig. 1. The status quo: subdivision of the Precambrian time-scale as proposed by the now dissolved Subcommission on Precambrian Stratigraphy (Plumb & James 1986; Plumb 1991; see also Lumbers & Card 1991). Boundaries were defined chronometrically in terms of absolute ages, and were chosen to coincide with perceived gaps in the global stratigraphic record. Whereas the subdivision of the Proterozoic has been formalized, that of the Archean Eon is merely 'recommended'. The lower boundary of the Archean remains undefined. The terms Hadean (Cloud 1972) and 'early Earth', both of which are in widespread use in the literature, are here included for completeness.

with their own inherent but independent uncertainties, should be employed to calibrate meaningful stratigraphic boundaries in absolute time. The ultimate result should be a calibrated 'natural' time scale for planet Earth that reflects first-order events and transitions in its complex evolution.

Proposal

To achieve this, the author proposes that a new international subcommittee on the Precambrian time scale and its calibration be formed under the auspices of ICS. The aim of this international subcommittee should be to propose, by 2008, a comprehensive and internally consistent, as well as practical, 'natural' time scale for planet Earth, complete with agreed upon 'golden spikes' and type sections (i.e. GSSPs, Global Stratotype Sections and Points; e.g. Harland *et al.* 1989) for all Precambrian eon and era boundaries, and, where needed, for those of periods (systems).

Such an international effort would help focus significant attention on key stratigraphic boundaries and type sections, and, in turn, will stimulate multidisciplinary science into the causes for specific boundaries and transitions, the fundamental processes involved, their rates, and their calibration in absolute time.

Building on efforts by the previous Subcommittee on Precambrian Stratigraphy (e.g. Plumb 1991), such a 'naturalizing' of the Precambrian time scale could largely preserve existing nomenclature, in so far as it has gained acceptance in the literature, while formalizing other eon and era names that are in widespread use today, e.g. the Hadean. Thus, by 2008, we would have, for the first time, a complete and natural time scale that reflects and communicates the entire, protracted and complex evolution of planet Earth.

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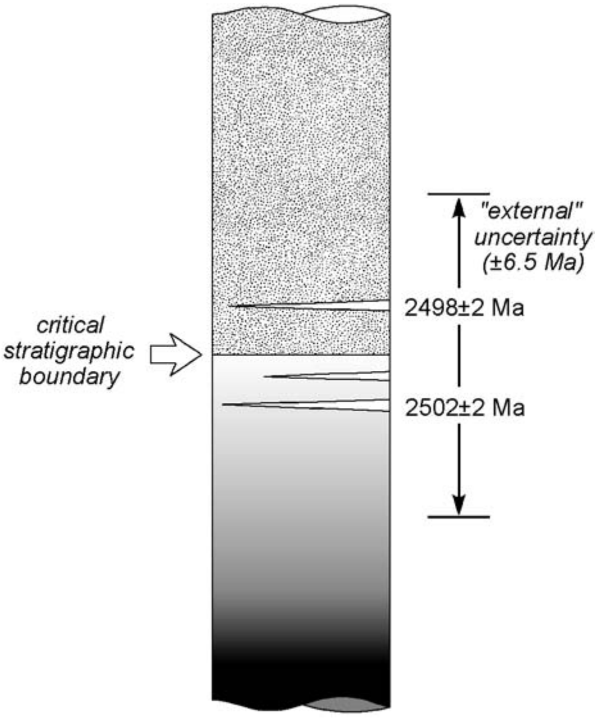

Fig. 2. Hypothetical stratigraphic section at or near the present chronometrically defined Archean–Proterozoic boundary. Note that the timing of an important stratigraphic feature (indicated by arrow), even when bracketed by precisely dated tuff layers, remains uncertain relative to an externally defined absolute age (i.e. 2500 Ma). The uncertainty range (vertical arrows) is shown at a 6.5 Ma level, but could be as high as 10 Ma. Rock strata at or near this boundary can therefore not be classified as Archean or Proterozoic relative to a boundary defined in absolute terms.

References

Allègre, C.J., Manhès, G. & Göpel, C. 1995: The age of the Earth. *Geochimica et Cosmochimica Acta 59*, 1445–1456.

Blake, T.S. & Groves, D.I. 1987: Continental rifting and the Archean-Proterozoic transition. *Geology 15*, 229–232.

Bleeker, W. 2003a: Problems with the Precambrian timescale: from accretion to Paleoproterozoic plate break-up. See http://www.nunatime.ca.

Bleeker, W. 2003b: The late Archean record: a puzzle in ca. 35 pieces. *Lithos 71*, 99–134.

Bowring, S.A., Ramezani, J. & Grotzinger, J.P. 2003: High-precision U-Pb zircon geochronology and Cambrian–Precambrian boundary. See http://www.nunatime.ca.

Cloud, P. 1972: A working model of the primitive Earth. *American Journal of Science 272*, 537–548.

Cloud, P. 1987: Trends, transitions, and events in Cryptozoic history and their calibration: apropos recommendations by the Subcommission on Precambrian Stratigraphy. *Precambrian Research 37*, 257–264.

Crook, K.A.W. 1989: Why the Precambrian time-scale should be chronostratigraphic: a response to recommendations by the Subcommittee on Precambrian Stratigraphy. *Precambrian Research 43*, 143–150.

Gradstein, F.M., Finney, S.C., Lane, R. & Ogg, J.G. 2003: ICS on stage. *Lethaia 36*, 371–378.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G. 1989: *A geologic time scale.* 263 pp. Cambridge University Press, Cambridge.

Ludwig, K.R. 2000: Decay constant errors in U-Pb Concordia-intercept ages. *Chemical Geology 166*, 315–318.

Lumbers, S.B. & Card, K.D. 1991: Chronometric subdivision of the Archean. *Geolog 20*, 56–57.

Nisbet, E.G. 1991: Of clocks and rocks – The four aeons of Earth. *Episodes 14*, 327–331.

NUNA. 2003: New Frontiers in the fourth dimension: generation, calibration and application of geological timescales. NUNA Conference, Geological Association of Canada; Mont Tremblant, Quebec, Canada, March 15–18, 2003. See http://www.nunatime.ca.

Plumb, K.A. 1991: New Precambrian time scale. *Episodes 14*, 139–140.

Plumb, K.A. & James, H.L. 1986: Subdivision of Precambrian time: Recommendations and suggestions by the commission on Precambrian stratigraphy. *Precambrian Research 32*, 65–92.

Trendall, A.F. 1991: The 'geological unit' (g.u.) – A suggested new measure of geologic time. *Geology 19*, 195 pp.

Windley, B.F. 1984: The Archaean-Proterozoic boundary. *Tectonophysics 105*, 43–53.

Appendix: specific criticisms of the present Precambrian time scale

- Subdivisions (Fig. 1) are defined in terms of arbitrary, round, 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; Crook 1989; Nisbet 1991; Bleeker 2003a).
- In its present form, the time scale is heterogeneous, being based on biostratigraphy, extinctions, and other key events in the Phanerozoic, and fixed, defined, absolute ages in the Precambrian. For instance, the youngest subdivision of the Proterozoic ('Neoproterozoic III', see Fig. 1) 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 the 'Cambrian radiation' dated at ca. 542 Ma (e.g. Bowring *et al.* 2003).
- Boundaries were chosen in perceived gaps in the stratigraphic record and thus are based on 'negative evidence'.
- Even in existing sections with sufficient datable tuff horizons, a precise absolute age (e.g. 2500 Ma) cannot be located due to the inherent uncertainty in decay constants (Ludwig 2000) 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 5–10 million years, relative to an externally defined absolute age, or another geochronometer; see Fig. 2).
- The proposed time scale was inadequately published (e.g. Plumb 1991; Lumbers & Card 1991), resulting in formal and proposed subdivisions (e.g. Neoarch-

ean, Fig. 1) 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 & James 1986). This further contributes to poor recognition and acceptance (e.g. what is the Calymmian Period, or the Eoarchean Era?). To illustrate this further: a search of the Georef Database (March 2003) for such terms as the Ectasian or Calymmian Period yielded zero results. Due to current interests in Neoproterozoic glaciation events, the Cryogenian faired slightly better and this term has been used in 14 recent papers.
- The present time scale is incomplete, leaving the lower boundary of the Archean undefined.
- Hence, the present time scale does do little justice to the first-order events that shaped the Earth-Moon system. It should include a Hadean eon (Cloud 1972; see Fig. 1), dominated by heavy bombardment, from ca. 4.51 to ca. 3.85 Ga; an additional eon ('Genesis'? Bleeker, in preparation), spanning the interval from initial accretion and differentiation to the Moon-forming giant impact event at ca. 4.51 Ga, would be the explicit realm of accretionary processes and allow for synchronization of the early terrestrial and lunar time scales.
- 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).
- The main positive outcome of the proposed Precambrian time scale (Fig. 1) has been that it has stabilized, at least temporarily albeit artificially, the debate on the age and significance of the Archean-Proterozoic boundary. This has facilitated, to some extent, the recent literature on the late Archean, but at the expense of clear logic and procedure (see above), as well as 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 occurred as late as 2.5 Ga or even later (e.g. Windley 1984; Blake & Groves 1987; Cloud 1987; Nisbet 1991; Bleeker 2003b).