The Balanced Billion

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A mid-Proterozoic stretch of Earth's history (roughly 1.8–0.8 Ga) has been called, non-affectionately, the "boring billion." The moniker was first inspired several decades ago by the apparent absence of any significant carbon isotope anomalies and was linked to the relatively dull interval between Earth's broadly two-step pattern in atmospheric oxygenation (Brasier and Lindsay, 1998; Holland, 2006). Other data sets from Earth's surficial environment during this time have been shown to be equally peculiar, including the disappearance of iron formation, notable absences of any large oxygenation events, phosphorites, or glacial and manganese deposits (Hoffman et al., 2017; Holland, 2006; Planavsky, 2014), and a billion-year lag between the oldest known Paleoproterozoic eukaryote fossils versus pronounced mid-Neoproterozoic eukaryotic diversity and ecological importance (Knoll and Nowak, 2017).

Oddities of this billion years (Fig. 1) come not only from records of surface evolution and palaeoenvironment but also from the solid Earth, including metamorphic style (a paucity of high-pressure conditions; Brown and Johnson, 2019) and either absences (ophiolites) or abundances (anorthosites) of specific igneous rock suites (Roberts et al., 2022). Recently, the mid-Proterozoic anomaly has even been suggested to be expressed as deep as mantle convection and as far flung as the Earth–Moon system, with the billion years suggested to respectively represent the transition from bottom-up to top-down mantle convection (Mitchell et al., 2022) and a remarkable flat-lining of Earth's rotational history at a constant ~19 h per day (Mitchell and Kirscher, 2023). Anomalies can be recognized as deep as Earth's core, because measured palaeomagnetic inclinations (which convert to palaeolatitude assuming a geomagnetic field model) deviate significantly from the expectation of a geocentric axial dipole (Veikkolainen and Pesonen, 2021).

In direct contrast to an eon of ennui, Earth's mid-Proterozoic tectonic record is anything but stagnant. The Grenvillian super-orogen is globally widespread (Condie, 2021) and anomalously deeply eroded (Liu et al., 2017). Regardless of whether individual components of that orogenic system involve collisions between continents during Rodinia assembly (Fig. 2) or are produced by long-lived tectonic accretion (e.g., Slagstad et al., 2018), the attractive temporal correlations between silicate rock weathering and paleoclimate variability in Phanerozoic time (Macdonald et al., 2019) might predict profound atmospheric CO_2 drawdown and glaciation during the Grenvillian interval at ca. 1000 Ma, as well as changes to atmospheric oxygen from pyrite weathering and burial. Instead, climatic stability through the Meso-Neoproterozoic transition highlights the important geochemical flux balances and restorative feedbacks that must have existed around the rock cycle encompassing magmatism, weathering, sedimentation, and metamorphism. Profound and rapid changes in Rodinia's paleolatitude (Evans, 2021) could contribute to repetitive episodic activation of such feedbacks.

In light of (1) the original evidence coming from a relatively stable carbon cycle, (2) the souring over

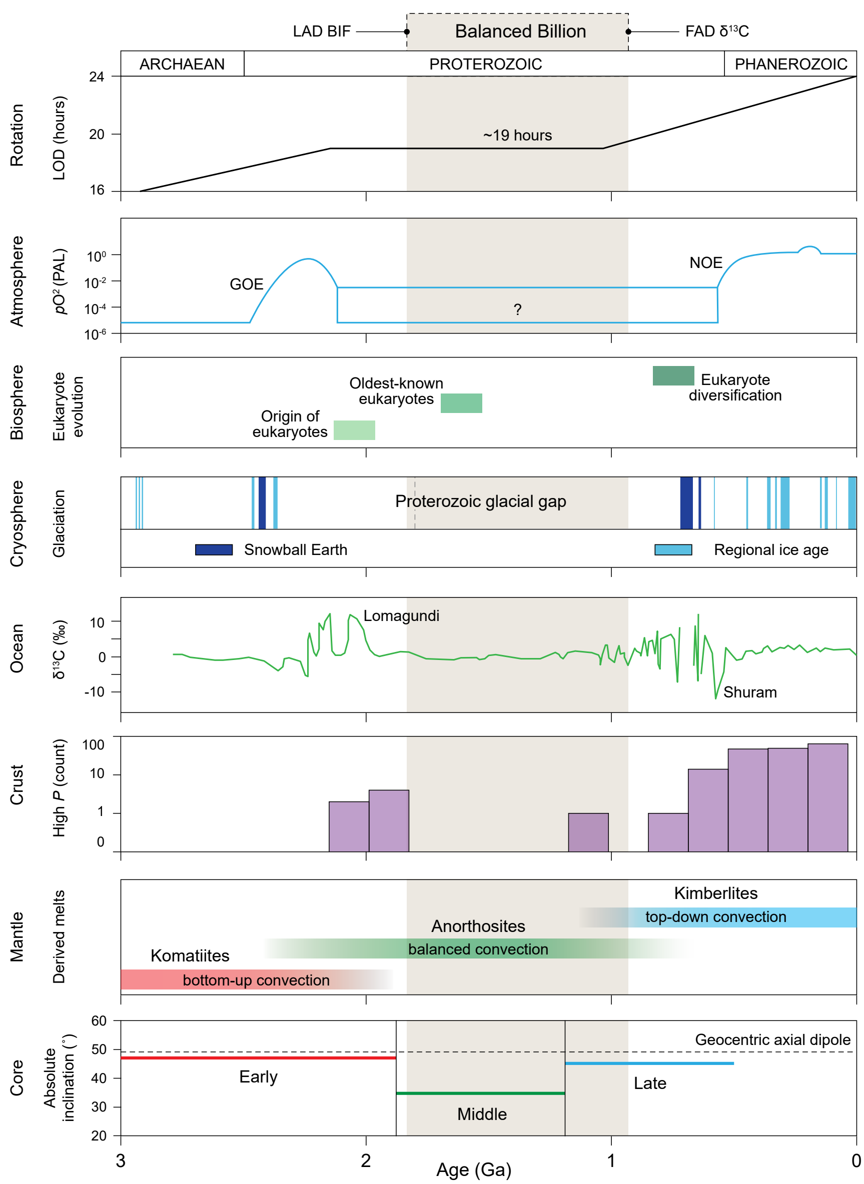

Figure 1. Proxy records from Earth's layers exhibit important idiosyncrasies during mid-Proterozoic time. LAD BIF = last appearance datum banded iron formation; FAD $\delta^{13}C$ = first appearance datum of significant carbon isotope excursions; LOD = length of day; GOE = Great Oxidation Event; NOE = Neoproterozoic Oxidation Event. These are proposed lower/upper chronostratigraphic boundaries of the Balanced Billion. See text for data sources.

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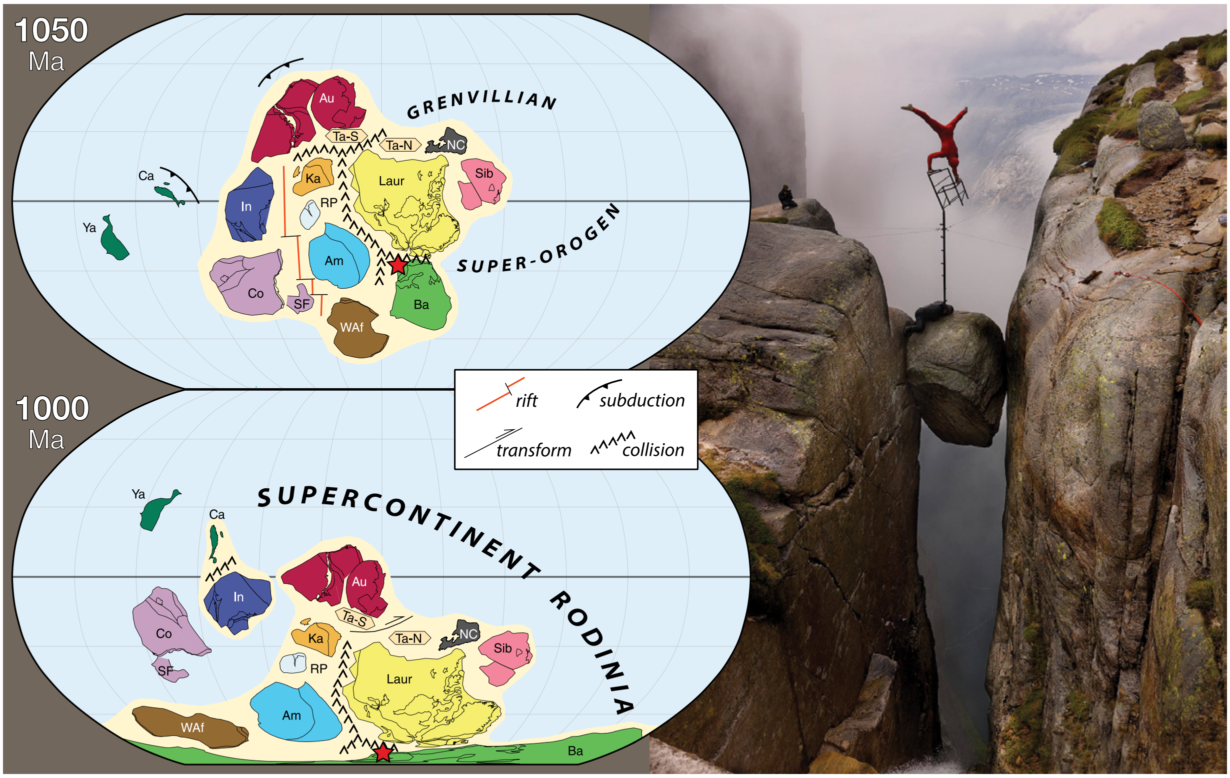

Figure 2. Left: Late Mesoproterozoic Grenvillian super-orogen, which consolidated the Rodinia supercontinent, represents a key component of the Earth-system balancing act required to maintain environmental stability at ca. 1000 Ma. Cratonic reconstructions from Evans (2021); Am = Amazonia, Au = Australia including Antarctic Mawsonland, Ba = Baltica, Ca = Cathaysia, Co = Congo, In = India, Ka = Kalahari, Laur = Laurentia, NC = North China, RP = Rio Plata, SF = São Francisco, Sib = Siberia, Ta-N = Tarim-North, Ta-S = Tarim-South, WAf = West African craton, Ya = Yangtze. Right: Kjeragbolten rock from the Sirdal Magmatic Complex in the Sveconorwegian orogen (Slagstad et al., 2018), denoted by a star in each reconstruction, epitomizes this delicate balance. Photo gratefully used with permission from Balance Eskil Rønningsbakken / Sindre Lundvold (https://www.kompanibliss.no/eskilbalance).

time of the unflattering term "boring billion," and (3) more recent additional clues coming from the deep Earth, we suggest a rebranding of the 1.8–0.8 Ga interval to the "Balanced Billion." The first benefit of this change is that it circumvents the subjectivity of what is "boring" as well as the strawman argument used repeatedly in the literature and news media when a new discovery overturns the concept of dullness. The second, more important benefit of this renaming is that it may inspire better recognition and quantification of mid-Proterozoic Earth system feedbacks—not only in the balanced paleoenvironment, but also in balanced mantle convection and a constant daylength due to balanced solar and lunar tidal torques. Whether these variegated processes are directly related is a frontier for understanding the interconnectedness of the deep-time Earth system and may lead to a better understanding of the long-delayed fuse in the rise of animals. Finally, as modern climate change trends toward increasing extremes (hotter/colder and drier/wetter), unlocking the secrets to the Balanced Billion may help society devise geoengineering solutions that mimic a time when Earth was more measured in its global change.

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