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The Eons of Chaos and Hades

C. Goldblatt[1], **K. J. Zahnle**[1], **N. H. Sleep**[2], **and E. G. Nisbet**[3]

[1]Space Science and Astrobiology Division, NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035, USA
[2]School of Earth Sciences, Stanford University, Stanford, CA 94305, USA
[3]Department of Earth Sciences, Royal Holloway, University of London, Egham, TW20 0EX, UK

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Abstract. We propose the *Chaotian Eon* to demarcate geologic time from the origin of the Solar System to the Moon-forming impact on Earth. This separates the solar system wide processes of planet formation from the subsequent divergent evolution of the inner planets. We further propose the division of the Hadean Eon into eras and periods and naming the proto-Earth *Tellus*.

1 Introduction

All Earth's geology depends on the composition and structure of the planet. This, in turn, depends on how the Earth formed in the violent beginning of our solar system. It is part provenance (where the Earth happened to form) and part chance (the stochastics of formation) (Stevenson, 2008). To describe the early Earth, we must bring the processes of formation into the same framework as its subsequent geological evolution. To this end, we propose the *Chaotian Eon* for the time of planet formation. Within this eon, the relative timing of events is now well understood though not constrained in absolute times. Accordingly, we propose a relative timescale in terms of era and periods.

The present (2009) International Commission on Stratigraphy timescale (http://www.stratigraphy.org/upload/ISChart2009.pdf) is rather sparse in its description of the earliest Earth, only noting the Hadean as an "informal" eon. Conversely, the description of this time proceeds rapidly, with increasing geochemical and theoretical study. The lack of a timescale leads to repeated and the unsatisfactory use of descriptive timing, e.g. "the time after the Moon-forming impact" and comparison of rocks and events based on imprecise radiometric dates. Subdivision of the Hadean will allow these to be described in their proper relative order.

2 The Chaotian

Planetary formation begins with the separation of solids from gas in the solar nebula and is followed by a period of hierarchic growth culminating in massive collisions between proto-planets (Chambers, 2004). For the proto-planets which became the Earth and the Moon, the last major collision was an oblique impact between a Mars-size body and the Venus-size proto-Earth, which ejected mantle material to form the Moon and left the planet molten (Canup, 2004). This cataclysm was the true birth of Earth. It separates our proposed solar system wide Chaotian Eon from the subsequent stratigraphic evolution of each inner planet.

Naming this eon, we emphasise that composition of the inner planets and, thus, their geology results from the chaotic interaction of planetary embryos. We further depend on Hesiod and Milton. Hesiod describes creation (*Theogony* 116-):

> "Verily at the first Chaos came to be, but next wide-bosomed Gaea [Earth]. From Chaos came forth Erebus [darkness] and black Nyx [Night]; but of Nyx were born Aether [the bright upper atmosphere] and Hermera [Day]…"

From Milton (*Paradise Lost II*, 907-):

> "…*Chaos* Umpire sits,
> And by decision more imbroiles the fray
> By which he Reigns; next him high Arbiter
> *Chance* governs all. Into this wilde Abyss,
> The Womb of nature and perhaps her Grave…
> Unless th' Almighty Maker them ordain
> His dark materials to create more Worlds"

Correspondence to: C. Goldblatt
(colin.goldblatt@nasa.gov)

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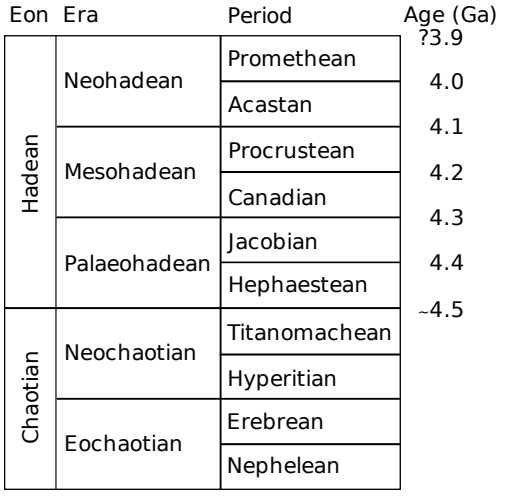

Fig. 1. Proposed time scale for the Solar System formation and the early Earth.

We suggest two Chaotian eras, each era with two periods (Fig. 1). The Eochaotian begins when the Solar Nebula became a closed system with respect to the rest of the giant molecular cloud and encompasses the agglomeration of the Solar System constituents from the nebula. It includes the Nephelean Period, for the cloud that is the nebula, and the Erebrean Period (Erebus, darkness) for the proto-Sun, yet to be luminous. The Neochaotian Era begins with the first light from the Sun. Its periods are the Hyperitian (the Titan Sun god Hyperion) for the time when gravitational collapse made the Sun's first light brighter than its subsequent main sequence (Sackmann et al., 1993), followed by the Titanomachean (the war of Titans), to encompass the collision of proto-planets to form our present set of planets.

Events and material from before the nebula are Prenephelean. We recommend that this term replace "presolar" for meteorite grains that formed before the nebula (Nittler, 2003), in contrast to within the nebula but before the Sun. Subdivision of Prenephelean time is beyond the scope of this paper and in the domain of astronomy.

The Moon-forming impactor has been named Theia (Halliday, 2000) after the Titan mother of the Moon goddess Selene. The proto-Earth remains unnamed. We suggest *Tellus*, for the Roman Earth goddess.

3 The Hadean

We propose the Hadean Eon (Cloud, 1976) began after Theia and Tellus collided to form the Earth-Moon system. The Hadean is restricted to Earth's geology, in contrast to the solar system wide Chaotian. We divide the eon into three eras (Palaeo-, Meso- and Neohadean) and each era into two periods.

The earliest Hadean had an extreme silicate and water vapour greenhouse, and a molten crust, which solidified in ∼10 My. We suggest Hephaestean (∼4.5 to 4.4 Ga) for the lower Palaeohadean (Hephaestus, the Olympian god of fire and blacksmith for the gods). For the upper Palaeohadean (4.4 to 4.3 Ga) we suggest the Jacobian after Australia's Jack Hills, which yield the earliest zircons. For the lower Mesohadean (4.3 to 4.2 Ga) we suggest the Canadian period, as crustal material dated back to 4.28 Ga is found in the Canadian Shield (O'Neil et al., 2008). For the upper Mesohadean, we suggest Procrustean (4.2 to 4.1 Ga) from Procrustes, whose bed fitted all life. As the lower Neohadean period (4.1 to 4.0 Ga), we suggest Acastan, after the 4.03 Ga Acasta Gneiss. From ∼4.0 to ∼3.8 Ga, the Late Heavy Bombardment saw the Earth and Moon struck by many asteroids great and small, the largest of which would have vapourised the ocean and exterminated any pre-existing life. Accordingly, we name the upper Neohadean period Promethean. Zeus vented his fury on Prometheus by bombarding the Earth (Aeschylus *Prometheus Bound* tr. P. Vellacott, closing speech):

> "The Earth rocks: thunder, echoing from the depth,
> roars in answer; fiery lightnings twist and flash...
> Sky and sea rage indistinguishably,
> The cataclysm advances visibly upon me,
> sent by Zeus to make afraid."

Current theory suggests the Late Heavy Bombardment was caused by the orbits of Jupiter (Zeus) and Saturn moving through a 2:1 resonance, providing the force to move the asteroids into the inner solar system (Gomes et al., 2005).

Whilst we have used ages to demarcate periods here, we are firmly of the belief that boundaries should correspond to specific events in Earth's history (as previously expressed by Nisbet, 1991). We hope that future work will tie our proposed boundaries to specific events, or modify the periods to be bounded by key events yet to become apparent.

The Hadean-Archean boundary is undefined. Nisbet (1982, 1991) suggested the origin of life but the timing of this is as yet unknown. The Late Heavy Bombardment seems intrinsically Hadean and the final impact of this would be the logical choice to terminate the Hadean (Zahnle et al., 2007), being a clearly identifiable event and heralding the start of the continually habitable period. However, this is unresolved in the terrestrial record and the 3.85 Ga rocks of Isua are commonly seen as Archean. A date of 3.9 Ga could be used provisionally, but risks splitting the Late Heavy Bombardment across two eons.

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