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Earth, Formation Early Evolution

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Synonyms

Keywords

Acasta, Akilia, basalt, continents, core formation, cosmochemistry, crust, early Earth, evolution of the atmosphere, geochronology, granite, Hadean, impact processes, isotopes, isua, Jack hills, late heavy bombardment, moon-forming impact, oceans, origin, planets, geochemistry, solar system, zircon

Definition

Earth formed as a silicate- and metal-rich body in the context of the other inner Solar System "terrestrial" worlds. In its early evolution, it separated into layers (core, ► mantle, ► crust) as a consequence of the chemical and mechanical properties of the materials that accreted to the Earth. The surface zone stabilized within the first 200 million years of Earth's existence, and has hosted geochemical cycles modulated in whole or in part by the presence of liquid water and an atmosphere since about 4.4 Ga ago.

Overview

Introduction

Earth is a natural and accessible planetary-scale laboratory to test ideas to be used in the search for life elsewhere in the Solar System and beyond. An understanding of Earth's origin is essential to the discipline of astrobiology, at least for the reason that this planet is the singular known repository of life. Studies of the origin and early evolution of Earth have undergone dramatic shifts in recent years, and have radically changed our knowledge of its formative time and how early events led to a habitable planet. This knowledge logically forms the basis of ongoing searches for other habitable solar systems in the galactic neighborhood. More than 400 planets around other stars have been documented by various methods (Schneider 2010) mostly within a sphere of space around 3×10^9 ly^3 (ly = light years). Yet it remains to be seen whether the specific orbital architecture of our Solar System that includes habitable rocky ► "terrestrial planets" with liquid water within a few astronomical units of a G-type star is exceptional or commonplace.

Early Earth was a vastly different planet from the one we are so familiar with today. The surface was heated from below by thermal conduction through the crust, and mainly from above by the muted radiation of the young Sun. At first glance it should have been uninhabitable. However, if there was liquid water, organic chemicals, and energy – all of which were present on this primeval surface – it is not unreasonable to suppose that the primordial chilled crust was the first platform in which processes leading to the emergence of life could have taken hold. Whatever the composition of the first crust was, the surface zone remained under a super-greenhouse atmosphere that kept temperatures within the stability field of liquid water.

The early terrestrial hydrous surface was continuously reworked by volcanic eruptions and impacts which mitigated its long-term survival which may be the reason why the oldest surviving terrestrial rocks or minerals date from 150 Ma after accretion (Harrison 2009). The long residence times of the oldest rocks in the crust means that almost any geological process could have been experienced by them. Over the intervening several billion years, weathering, denudation, erosion, ► metamorphism (thermal, chemical, pressure-induced, or all of the above), subduction, re-melting, and other crustal recycling processes have been at work to consume all but a minute fraction of what once existed from the first billion years of geologic time. Investigations focused on the origin of the hydrosphere, and when the crust evolved into the current basaltic (oceanic) and granitic (continental) dichotomy rests almost completely on information gleaned from a few meager rock and mineral scraps of the oldest surviving terranes (Blichert-Toft and Albarede 2008). Au2

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Au3

That by 4.0 Ga the basaltic and the granitic crust was established on Earth and oceans, as well as a rock cycle and the generation of sediments, is directly supported by the existence of metamorphosed remnants of granitoid rocks and marine sediments preserved from that time. Yet older evidence from the geochemistry of detrital zircons tracks back to 4.38 Ga, and shows that oceans and plate boundary processes (possibly plate tectonics?) could also have been present in the Hadean (Hopkins et al. 2008). Hence, the old prevailing view of a dry and molten landscape blasted by sterilizing impactors and intrinsically incapable of hosting the life until after 3.8 Ga has been swept away by new data. The new view of the Hadean eon (4.5–3.85 Ga) and subsequent Eoarchean (3.85–3.6 Ga) is a far more procreative one than was previously realized as more information has been forthcoming from this formative time (Fig. 1).

Early Solar System, Earth, and Moon

The age of the Solar System is calculated to be about 4.567 Ga (Connelly et al. 2008) based on geochronological studies of the earliest solids that are native to the Solar System, and which crystallized in the solar nebula before their eventual incorporation into meteorites. The paradigm for ► solar system formation begins with the collapse of part of a giant molecular cloud (Safronov 1969) that itself formed from gas and dust expelled in the explosion of one or more massive stars. While the exact mechanism(s) responsible for initiation of nebular collapse are unclear, nearby supernova explosions played a role in the initial gravitational/mass instabilities of the cloud based on the presence of the daughter products of some extinct short-lived nuclides in the oldest solids. Direct astronomical observations of giant molecular clouds containing young stars show that disk collapse and probable incipient dust grain formation around such stars is commonplace (Pascucci et al. 2009). In the planet-forming process, these grains aggregated into larger objects and eventually to planetesimals that were the building blocks of the planets.

A detailed chronology of the earliest events in the Solar System, which span the time from the first solids, through the origin of the planets, and ultimately to the appearance of the crust, ► hydrosphere and biosphere, will long be an area of intense study. The physics of Earth accretion has been explored in detail with sophisticated dynamical tools that model the interactions of planetesimals that led to growth (and in some case destruction) of ever-larger bodies. Numerical simulations of terrestrial planetary growth succeed in modeling the formation of planets of the size and distribution as Mercury, Venus, Earth, and Mars (Wetherill 1994). Such models show that most of the mass of the Earth accreted in 10 Myr, but that there is an accretionary tail that extends for an additional 100 Myr. Most of these dynamical models seem to indicate that the colliding planetesimals that built the terrestrial planets came from beyond Mars' orbit, or well beyond 2 AU (astronomical unit), and delivered volatile elements and compounds to the intrinsically dry, hot, inner solar system well inboard from the solar system's "frost line" in the vicinity of the asteroid belt. The climaxing event in the Earth's formation and earliest evolution is the origin of the Moon which was the result of the last big impact to affect the Earth.

The current paradigm favors lunar origin no earlier than about 30 Ma into the history of the solar system (i.e., from what is termed "t-zero" at 4.567 Ga). Model studies indicate that the Moon originated from a massive collision of the proto-Earth when our planet was about 90% of its present mass ($\sim 5.4 \times 10^{24}$ kg), with another planet of about Mars' mass (6.5×10^{23} kg). Earth's current mass is 5.974×10^{24} kg, and that of the Moon is 7.35×10^{22} kg, so that it seems that mass-loss from the impact process was negligible. The impact was so energetic and deeply destructive that it yielded a dense, hot, CO_2-rock vapor-steam atmosphere of hundreds of bars on top of a vigorously convective magma ocean that occupied most of the Earth's interior. An orbiting ring of super-hot devolatilized rock vapor coalesced into the Moon (Canup and Asphaug 2001). It is worth noting that in such an event, Earth would actually have plotted on the well-known Herzprung–Russell diagram that is normally used to relate luminosities of various classes of stars over the Sun's luminosity against a star's surface temperature. The Moon-forming impact raised the whole Earth's temperature to that of a small red star (>2300 K) for several thousand years. For the neo-formed Earth, most cooling models indicate that the hydrosphere re-condensed out of the atmosphere in less than 10 Myr (Sleep et al. 2001). It has been suggested that oceans were present on the proto-Earth prior to the Moon-forming event (Abe 1993), but we will never know this for sure. If there was a primary hydrosphere, it was wholly vaporized by the ► Giant Impact and did not re-stabilize into a "secondary hydrosphere" until later when the surface cooled to the point where liquid water could begin to pool on a thick (?) and dense primordial "chilled crust" of likely ultramafic (Fe- and Mg-rich) composition at the top of the magma ocean (Arndt and Chauvel 1991). It is possible that a primordial crust and watery veneer of the post-impact Earth existed as early as about 35 million years after to, or around 4.53 Ga. Maybe, record of this primordial crust will never be found since all traces of it are expected to have been destroyed (cf. Carlson and Boyet 2009).

Not until 150 Myr after to do we have direct evidence of the first (granitoid) crust from ancient terrestrial zircons (at 4.38 Ga), and only 500 Myr after that do we have the first direct evidence of surface conditions from marine sediments and basaltic lavas (ca. 3.83 Ga). Hence, the geologic record from actual rocks (as opposed to detrital zircons) only extends back from the present through ~88% of Earth history. The Hadean zircons bring this record up to a remarkable 95%. It is not impossible that older actual rocks will be found, but at present the most ancient units are slightly more than 4 Ga old and found in the ► Acasta Gneiss Complex of northern Canada (Bowring and Williams 1999). A gallery of ages for the next oldest rocks begins at the 3.77–3.87 Ga Isua Supracrustal Belt and the Akilia association (Nutman et al. 1996) in southern West Greenland, and in Canada at the ca. 3.75 Ga Nuvvuagittuq Supracrustal Belt in northern Quebec (Cates and Mojzsis 2007). All of these outcrops are dominated by highly-deformed tonalite-trondhjemite-granodiorite (TTG) gneisses that often (but not always) host supracrustal enclaves of amphibolites and other lithologies. Amphibolites in these cases are the metamorphic equivalents of volcanic and intrusive igneous rocks such as basalt, gabbros, and ► komatiites, and they sometimes host rare metamorphosed sedimentary rocks such as ferruginous siliceous schists (banded iron-formations; BIFs). Pillow lavas in the Isua belt unambiguously attest to the presence of subaqueously erupted basalts.

Early Atmosphere

The Sun has increased its luminosity with time as its core increased its density with the transmutation of hydrogen to helium by nuclear fusion reactions. Standard models for the behavior of stars in the Main Sequence predict that the Sun was only about 70% as bright in the visible part of the electromagnetic spectrum as it is now when it entered the Main Sequence 100 Myr after t0, or around 4.46 Ga (Ribas et al. 2005). The Sun had only brightened slightly more to ~77% present values by the time of the earliest morphological evidence of life in the form of biosedimentary structures (stromatolites) and purported microbial microfossils appears much later in the rock record, from 3.5 Ga in the Dresser Formation in Western Australia (Van Kranendonk 2006). A dimmer early Sun remains a long-standing and mostly unresolved problem for atmospheric models that seek to keep the early Earth warm enough for liquid water to remain stable (Sagan and Mullen 1972). So far, it is very difficult for these models to account for a warm early Earth, and no atmospheric models succeed in keeping ancient Mars above 0°C. In the absence of abundant and efficient greenhouse gases such as water vapor, CO_2, CH_4, and NH_3, the Earth before about 2 billion years ago ought to have been ice-covered down to the equator. The only credible solution to account for oceans of liquid water is to have a denser atmosphere rich in powerful greenhouse gases compared to anything that has existed in Phanerozoic time; relatively speaking, there has been but a small variation in greenhouse gases – well within several tens of percent of present atmospheric concentrations – over the last 500 Myr (Berner 1991).

Broad estimates for average surface temperature of the early Earth depend strongly on what plausible limits can be placed on CO_2, CH_4, and NH_3 abundances, and the sources and lifetimes of these gases in the atmosphere. If all carbon currently present in Earth's crust as carbonate and organic matter was oxidized to CO_2 and stored in the atmosphere (Holland 1984), as happened on Venus, the resulting 60–100 bar CO_2 greenhouse could have produced surface temperatures to 180–230°C even as far back as 4.4 Ga (Abe 1993). If pCO_2 values were reduced to around 0.5 bar (still a 1500-fold increase from modern values) by massive silicate weathering and carbonate sequestration in oceans, as well as enhanced volcanism and plate recycling, estimates for Hadean-Eoarchean surface temperatures are reduced to near 0°C. Was the early Earth warm or cold? Controversy prevails over the interpretation of proxy temperature data from isotopes of oxygen (Knauth 2005) and silicon (Robert and Chaussidon 2006) in cherts. These data have been interpreted to indicate seawater temperatures above 50°C back to about 3.5 Ga. Atmospheric models constructed to simulate conditions on the early Earth are inconsistent with the geochemistry of ancient sediments deposited in a hot ocean. Instead, model outputs for these atmosphere simulations almost always call for temperatures at or below the freezing point of water. Hence, much more work remains to be done to resolve this fundamental discrepancy between model and experiment.

Late Heavy Bombardment and its Effects

During the epoch of heavy bombardment in the late Hadean (4.2–3.9 Ga), impacts modified geothermal, geochemical, and geomorphologic conditions at the surface. Big (hundreds of kilometers in diameter) impactors can transform a globally habitable Earth into a surface cauterized by a hundred meter thick film of molten rock. However, only the largest of these impacts would have affected more than a hemisphere, leaving the rest relatively unscathed.

Almost all of our information about early bombardment of the inner Solar System comes from studies of the surface of the Moon. That object displays abundant evidence for an intense impact flux at some time between the formation of the lunar highland crust (ca. 4.5 Ga) and the outpourings of lava into the mare basins (>3.1 Ga). Ages recovered of fragments of the ancient highland crust returned during the Apollo program from have been interpreted to represent either a short and intense ►"late heavy bombardment" (LHB) period at 3.9 Ga (Ryder 2002) or the tail end of an extended post-accretionary bombardment (Hartmann et al. 2007). Some authors have argued that the absence of lunar impact melt ages older than about 3.9 Ga requires that the Solar System was relatively quiet from the Moon-forming impact to the LHB (Ryder 2002). Independent verification of an LHB comes from studies of lunar meteorites that record impacts from the 3.9 Ga timeframe (Cohen et al. 2000). If so, why was there an LHB? The exact mechanism is unknown, but early gravitational resonance interaction between Jupiter and the other outer planets has been implicated (Gomes et al. 2005).

Although it is generally agreed that massive collisions between Earth and space debris were fundamental formative agents to all of the planets in the first few hundred million years, no clear terrestrial record of the LHB has so far been found (Anbar et al. 2001). Earth is a larger body than the Moon, with stronger gravity to attract bolides and more surface area to be struck. By inference from the well-preserved lunar and Martian records, Earth's crust during the LHB ought to have been pummeled to dust. Although basic features of such an impact environment have been investigated via numerical models, the specific consequences of these collisions for the crust, and the overall effects they had (destructive or procreative) to the emergent biosphere, are an area of intense current study. Numerical modeling studies of the consequences to the Earth of impacting after the Moon-forming event (ca. 4.53 Ga) show that temperatures planet-wide were never brought to levels necessary for global sterilization (Abramov and Mojzsis 2009).

Early Hydrosphere

Earth's surface zone, from the top of the atmosphere to mid-crustal depths, has more than one ocean volume's worth of liquid water (∼3 × 10–2% of Earth's mass). But uncertainty lingers over Earth's total inventory of water (Mottl et al. 2007), and the ultimate source of Earth's water also remains ill-constrained: it could be from intrinsic outgassing during planetary growth of water supplied in accreting planetary material, or it could have come subsequently from accreting meteoritic or cometary matter (Albarede 2009). Probably all of these are correct. The availability and long-term stability of liquid water over geologic timescales is probably the determining factor that controls habitability of a planet. Deciding whether Earth is relatively "dry" or "wet" as terrestrial planets go (Raymond et al. 2004) will depend on discoveries from future extra-solar systems by remote observations. Direct evidence for abundant surface water on Earth appears to extend as far back as the beginning of the geologic record.

Mildly deformed and metamorphosed volcanic and sedimentary rocks that formed subaqueously are found in 3.49 Ga rocks in the Pilbara craton of Western Australia and the Barberton greenstone belt of South Africa (Van Kranendonk 2006). However, all rocks older than about 3.6 Ga are highly-deformed gneisses that have experienced pervasive metamorphism and recrystallization. The most ancient gneissic terranes consist of more than 90% of intrusive rocks and most of these are of granitoid (TTG) composition. These rock types, especially the tonalites and trondhjemites, are derived from Na-rich and K-poor melts of hydrated mafic (usually oceanic) crust following transformation into garnet amphibolite or eclogite. As with most (but not all) present occurrences of TTGs, these rocks probably formed in subduction zones (Martin et al. 2005). In older terranes such as the West ►Greenland Itsaq Gneiss Complex (Nutman et al. 1996), multiple generations of granitoids of different ages and compositions host enclaves and tectonized rafts ranging in size from meter- to kilometer-scale of yet older "supracrustal" rocks which constitute something less than 10% of the mapped outcrops. The oldest terrestrial rocks are found in the 4.03 Ga Acasta Gneiss Complex, but these deep-seated (7 km?) intrusive igneous protoliths do not convey direct information about the surface environment (Stern and Bleeker 1998). Only when further discoveries are made of pre-3.6 Ga gneisses and supracrustal enclaves, will more direct information will be revealed about the early Earth.

The oldest rocks with surviving volcanic and sedimentary structures indicative of a marine origin form a tiny amount of the dominantly amphibolite (metamorphosed basalt) rocks of the ca. 3.8 Ga Isua Supracrustal Belt which is part of the Itsaq Gneiss Complex. Within some low-strain zones of the amphibolites, clear pillow structures are preserved, and because such structures form when lavas erupt under water, they directly establish that liquid water was present when the Isua lavas erupted. At the Isua Supracrustal Belt, associated with these rocks are quartz–magnetite schists that in places are preserved as banded iron-formations (BIF) with genuine sedimentary banding; such sedimentary rocks also formed in liquid water (Klein 2005). The Isua Supracrustal Belt contains the oldest undisputed terrestrial record of a marine environment.

Of the other pre-3.8 Ga gneisses and amphibolites in Greenland, none has been more closely scrutinized than the ca. outcrops on the island of Akilia (Manning et al. 2006). Rocks on Akilia include the polyphase Itsaq Gneiss Complex with ages that span 3.87–3.62 Ga (Nutman et al. 1996). Unlike the Isua rocks which encompass at least 200 km^2 of continuous exposure and preserve some primary structures, the gneisses on Akilia are very highly deformed. Although the Akilia association is more widespread with occurrences of enclaves throughout the southernmost part of the Itsaq Gneiss Complex, they are at much smaller scale and are less coherent than the Isua belt. At best, meter- to tens of meter-scale enclaves of amphibolites and ferruginous quartzites are present locally (Cates and Mojzsis 2006). Enclaves of Akilia quartz-magnetite-pyroxene schists are have been interpreted as metasediments, and they share the trace element signatures of BIF from Isua and elsewhere (Manning et al. 2006). They preserve Fe isotope fractionations unlike igneous rocks and similar to Isua BIF (Dauphas et al. 2004). Several workers have proposed a minimum age of 3.83–3.85 Ga for the Akilia supracrustal rocks (Nutman et al. 1996; Manning et al. 2006), but this age, as well as the interpretation of these rocks as an originally volcano-sedimentary succession, has been stridently challenged (Whitehouse et al. 2009).

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Other localities with >3.7 Ga volcanic or sedimentary rocks are found in the northeastern most margin of the Superior Province in the Nuvvuagittuq Supracrustal Belt (previously known as Porpoise Cove). The northeastern Superior Province in northern Quebec is dominantly composed of TTG and dioritic gneisses containing rafts of older amphibolitized supracrustal rocks (Cates and Mojzsis 2009). As in West Greenland, these tend to comprise linear belts of metamorphosed sedimentary and extrusive igneous rocks that in rare cases preserve primary sedimentary and volcanic structures. Detailed mapping and geochronology of these units confirms a minimum age of 3.75 Ga for an 8 km^2 enclave of mafic- and ultramafic amphibolites, quartz-magnetite BIFs, quartz-amphibole schists, and other possible detrital sediments at Nuvvuagittuq (Dauphas et al. 2007).

Plate tectonics mechanisms can be viewed as an adequate, but not exclusive, means of generating the ancient continental crust preserved in the West Greenland and northern Canada terranes cited above. Alternatively, mantle superplumes (Albarede 1998) could have played at least a supporting role in the generation of this crust. Future detailed studies of the oldest terranes will test the idea that plumes, ► plate tectonics, or some hybrid model can account for the structure and geochemistry of the oldest preserved crust.

Did Plate Tectonics Work Out in the Early Archean?

Within the most ancient terranes that have been mapped at the appropriate detail and which have been subjected to extensive geochronological studies, intrusive, volcanic and sedimentary rocks of different ages are juxtaposed. Some authors have argued that this kind of geologic style preserved in West Greenland is a consequence of a compressive regime and plate boundary processes that extended back to 3.8 Ga or even earlier in the Hadean (Kurenaga 2008; Davies 2008). Like modern oceanic arc evolution, many ancient but much better-preserved terranes, such as the 3.5 Ga Pilbara craton, record permissive evidence of tectonic evolution from plate- or plume-related crust formation to episodic growth of continental crust through the emplacement of tonalites derived from partial melting of hydrated basalt (Van Kranendonk et al. 2007). The granitoids intruded sequences of basalt with ferruginous-siliceous sedimentary layers, a scenario remarkably similar in both structure and chemistry to many contemporary island arcs above subducting oceanic slabs (Kato et al. 1998).

Did Plate Tectonics Exist in the Hadean?

Zircons older than 3.9 Ga are mostly found at Jack Hills and Mt. Narryer in the Narryer Gneiss Complex, Yilgarn craton, Western Australia (Froude et al. 1983; Compston and Pidgeon 1986). Others have been recovered from elsewhere in Western Australia (Wyche et al. 2004) and in scattered localities worldwide (Mueller et al. 1998). Many of the most ancient Jack Hills zircons contain inclusions of quartz, muscovite, and other phases produced from silica-saturated igneous rocks, meaning that ► granites existed before 4.1 Ga (Hopkins et al. 2008). Low temperatures of formation, consistent with plate underthrusting, have been determined using titanium thermometry on >4.0 Ga Jack Hills zircons. Many the Hadean zircons also have isotopically heavy oxygen ($\delta^{18}O$ up to +7.3 ‰), which supports the view that melting of hydrated crust produced the pre-4.0 Ga granites and that some were contaminated by subducted (?) sediment (Mojzsis et al. 2001). Although the details of this hypothesis remain the focus of debate, the viewpoint of a hospitable, water-rich Hadean Earth leads to a number of predictions:

- Separation of crust into continental (granitic) and oceanic (mafic) styles prevailed since the earliest times.
- Conditions were conducive to the long-term sustainability of biological activity.
- Preservation of Hadean zircons shows that Earth had crystallized its magma ocean and formed stable crust by 4.4 Ga and that no catastrophic impacts wholly destroyed that crust. Although the nature of the primordial crust and the composition of the source rocks of the 4.4–4.0 Ga zircons remain unresolved (Trail et al. 2007), there is now little doubt that the Hadean Earth could have supported life.

Finally, although no rocks and minerals are preserved from Earth's first 150 million years, there ought to be echoes of its prior existence. Recent work from both Nd and Hf isotope signatures from 4.4–3.5 Ga rocks and minerals provide evidence of planetary-scale events during Earth's first 100 million years. These events that entailed major chemical fractionations in the mantle, perhaps as a consequence of an early magma ocean and the establishment of the proto-crust in the early Hadean, occurred prior to about 4.3 billion years ago or even earlier (Caro et al. 2006; Blichert-Toft and Albarede 2008; Tessalina et al. 2010).

See also

► Acasta, Gneiss
► Akilia, Greenland
► Archaean, Environmental Conditions
► Archaean, Eon
► Archaean, Mantle
► Archaean, Tectonics
► Atmospheric Envelope/Primitive
► Chondrite
► Condensation Sequence
► Continental Crust
► Continents
► Cool Early Earth
► Cosmochemistry
► Crater, Impact
► Craton
► Crust
► Earth atmosphere, Origin and Evolution of
► Earth, Age of
► Ecopoiesis
► Evolution, Planetary
► Exoplanet
► Exoplanet Detection (Including Radial-Velocity Planet Detection and Surveys)
► Extreme Environment
► Geochronology (methods)
► Geological Time Scale
► Geology, Timescale
► Geothermal Gradient
► Giant Impact
► Granite
► Greenland
► Greenschist, Facies
► Greenstone Belts
► Habitability
► Hadean (Eon)
► Heat Flow (Planetary)
► Hydrosphere
► Impact Basin
► Impact Melt Rock
► Isua Supracrustal Belt (West Greenland)
► Jack Hills (Yilgarn, Western Australia)
► Komatiite
► Late Heavy Bombardment
► Late Veneer
► Late-Stage Accretion/ Chaotic Growth
► Life
► Magma Oceans (Planetary)
► Mantle
► Mantle Plume (Planetary)
► Mantle Volatiles
► Mantle, Oxidation of
► Mare, Maria
► Metamorphism
► Meteoritic Impact (Biological Effect)
► Nice Model
► Nuvvuagittuq (Porpoise Cove) Greenstone Belt
► Ocean, Chemical Evolution of
► Ocean (on Early Venus)
► Ocean Planets
► Ocean, Origin of
► Oxygen Isotopes
► Planetary Atmospheres
► Planetesimals
► Plate Tectonics
► Prebiotic Chemistry
► Precambrian
► Primordial Heat
► Solar Luminosity
► Solar System Formation
► Solar System (Geochronology)
► Solar System, Inner
► Stellar Evolution
► Terrestrial Planet
► Warrawoona Group

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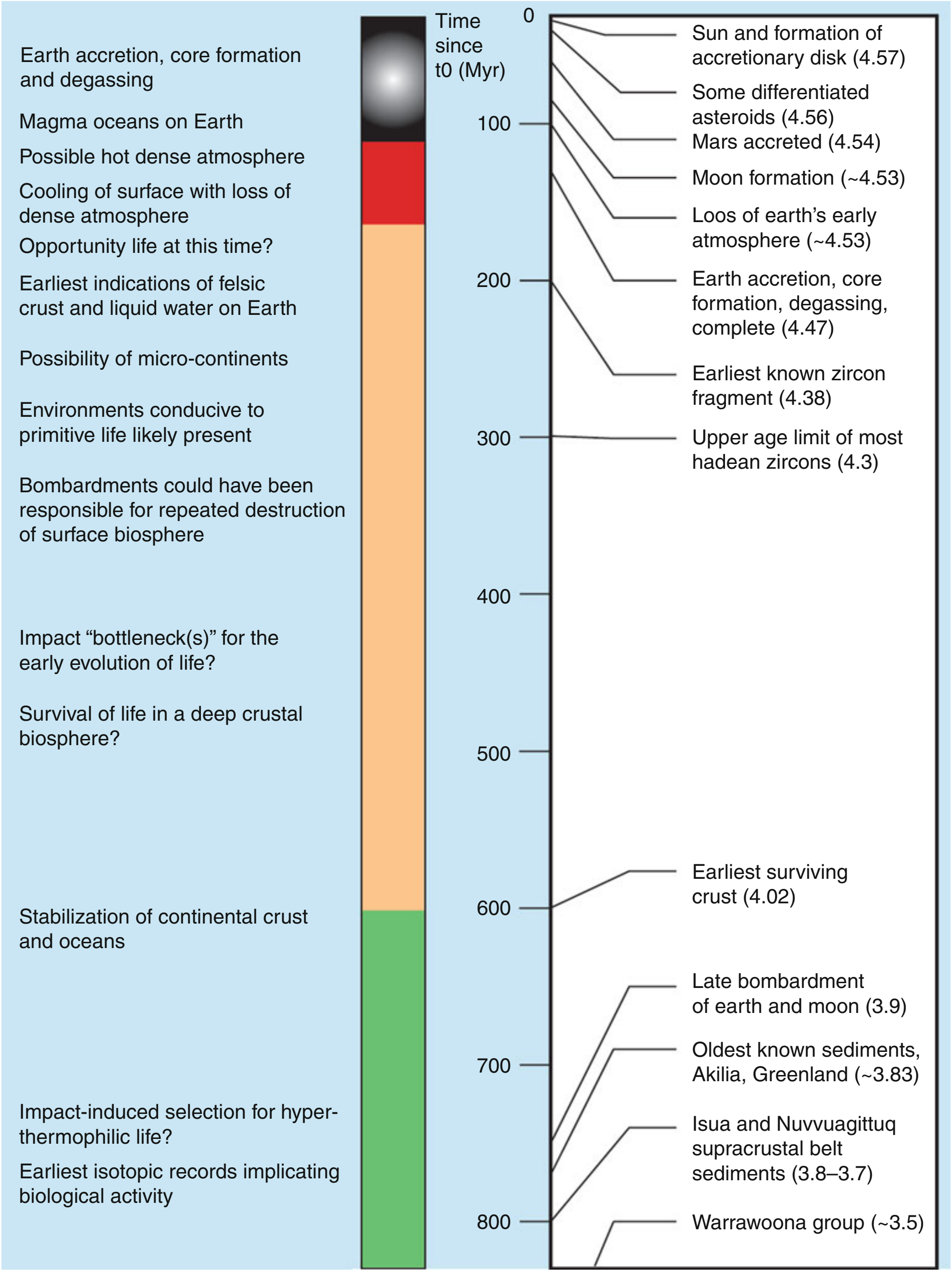

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Earth, Formation Early Evolution. Figure 1

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