The Early Earth: t_0 plus 10^5 to 10^8 years

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Solar system's evolution changed dramatically at various stages and on different time scales. The first 10^5 years sees the central accretion of mass due to centrifugal effects and possibly reaching the final stages of accretion of the Sun, which has the gravitational dominance of the Solar system. At about 100,000 years the Sun reaches enough mass for ignition (e..g, deuterium fusion), the earliest preserved condensates (CAI) are formed, and planetismal formation is rapidly occurring. At 10^6 to 10^7 years disk evolution, there is loss of the nebula envelop (circa 3 to 6 Ma after t_0), formation of chondritic parent bodies, growth of the planets (e.g., Mars is estimated to have mostly formed in 2 Ma), and a likelihood of gas giant migration (i.e., Jupiter coming into Mars orbital distance ($\sim$2 AU) followed by its outward migration assisted by Saturn). This migration of the gas giants (known as the *Grand Tack* model) causes considerable mass mixing in the closest 5 AU out from the Sun. At this time planetesimal form and combine to make planets and theses bodies are undergoing core-mantle differentiation. At one to a few 10^7 years the disk is dissipated and the terrestrial planets take shape. By 10^7 to 10^8 years and beyond Moon formation, late accretion, vigorous convection, and the crust and atmosphere develop.

I. SUMMARY

1 - 10^5 yr: Some triggering event initiates solar system formation
10^5 yr: The Sun ignites, CAI, planetismals, chondrules, chondrites(?), planets
10^6 -10^7 yr: disk evolution, planet accretion, core formation, magma ocean(s), Moon fm???
10^8 yr: Moon formation, late accretion, vigorous early convection (?), crust, atmosphere?
few 10^8 yr: crust formation, surface processes, atmosphere/hydrosphere,

A. *t_0 plus 100,000 years*

- What is t_0 and how is it defined: age of CAI formation
- WR, SN, AGB, vs Neutron-star mergers as sources of short lived nuclides: e.g., ^{107}Pd vs ^{182}Hf
- Distribution and temporal evolution of gas in disk: condensation sequence
- Timescales of planetismals, chondritic parent bodies, and planet formation
- Secular variation in disk composition: Solar composition - inner vs outer shell?
- Where and when did planetismals and Jupiter form? Nice model, role for gas giants, volatiles in the solar system

B. *10^6 -10^7 years after t_0 (CAI formation)*

- What is t_0 and how is it defined: age of CAI formation
- what is the role of short-lived isotopes? [Chondrite fm ages]
- Redox vs time: secular variation in disk composition
- Rapid planetary differentiation: stories from ^{182}W in iron meteorites
- Astro-mineralogy of accretion disks: Mg/Si of planets
- Earth's most significant differentiation event: core formation
- Grand Tack model: role for gas giants in shaping "late accretion"
- Did collisional erosion play a role in shaping Earth's composition?

C. *few 10^7 to 10^8 years after t_0 (CAI formation)*

- Moon formation: when, how many, how deep? What is the evidence?
- Magma oceans: when, how many, how deep? The ?evidence??
- Differentiation of the BSE (bulk silicate Earth): formation of a surface crust
- Core-mantle exchange: what has happened since core formation?
- Early vs late accretion rates: what is the *(dM/dt)* (Mass)
- Evolution of the atmosphere and hydrosphere

II. *VOLATILE HISTORY AND INVENTORY OF THE EARTH (AND MOON)*

- Moderately volatile elements: alkali metals, S, "lithophile/siderophile" elements
- Mn-Cr isotope system: timing of volatile depletion
- Highly volatile elements (H_2O, CO_2, Noble gases)
- Moon has ~10 times less Moderately volatile elements (e.g., K/U, Rb/Sr)

III. *1^{st} ORDER ENERGY EQUATION FOR THE EARLY EARTH*

- $KE = \frac{1}{2}\, mv^2$; incoming velocity at ~20 km/s Earth's mass 6 x 10^{24} kg, $\therefore$ KE = 10^{32} J
- Core fm: $\downarrow$ mass of core 2 x10^{24} kg, settling velocity — maybe ~2 m/s, $\therefore$ KE = 10^{25} J
- Energy of Giant impact event (as above)
- What is the heat dissipation rate *(dT/dt)*: 50, 100, 150 K/Ga - *significant unkown!*

— Did we have a blanketing atmosphere?

IV. *TIMING OF EARTH'S DIFFERENTIATION*

- Age of the core: ^{182}W vs U-Pb isotopes
- Age of Moon formation: oldest lunar rocks
- Magma ocean: Did it happen? Yes; Are there products remaining from Primordial Layers(?)
- Age of crust formation: oldest minerals; Mean age of the Continental Crust: "crust growth curve"
- Relative ages of DM (Depleted Mantle) and EM (Enriched Mantle)
- Sr, Nd, Pb isotopes: 1.8 Ga; Noble gas isotopes: 4.4 Ga

V. *CORE: FE-NI ALLOY + "OTHER" - THE BIG UNKNOWNS*

- Physical attributes of the Outer Core & Inner Core
- Birch's Law: bulk sound speed vs mean atomic number; Candidate light elements: H, C, O, Si, S
- Density contrast IC (inner core) vs OC (outer core); Age of Inner Core and core energy budget
- Secular record of the age and strength of the geodynamo
- Core-Mantle exchange: did/does it happen, evidence

VI. *NOBLE GASES: THEY CARRY A SPECIAL STORY*

- Xe and early Earth: ^{127}I and ^{244}Pu - ^{129}Xe and ^{136}Xe, respectively
- ^{40}Ar, K/U and degassing: understanding volatiles and heat in the Earth
- ^{4}He (and ^{21}Ne) flux: He-Heat flow paradox