Wed. Oct. 25, 2017

- Reminder -- extra lecture next Friday (not this Friday) at noon
- Reading: Ch. 5 (Atmospheres) from Wood plus lunar papers for Friday

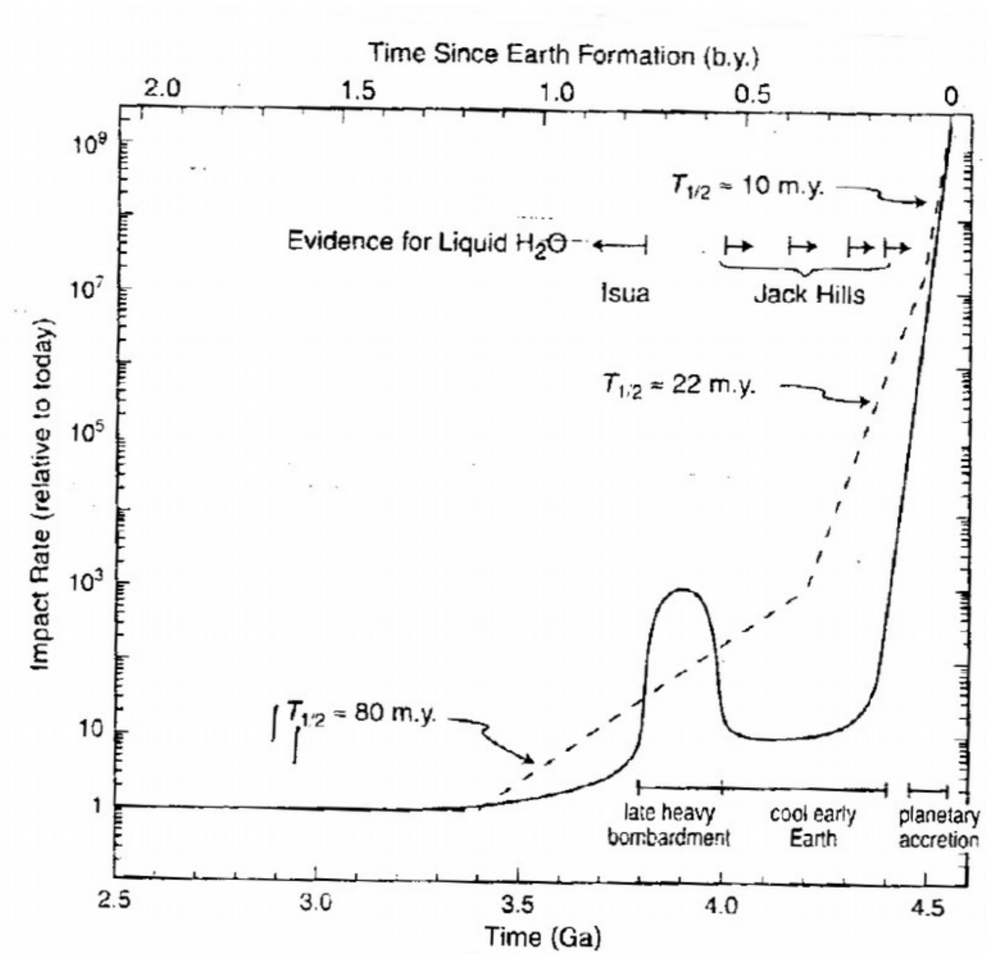
- Today:
  - Plans for midterm (final? discussion)
  - Topics for last 1/3 of semester (final? discussion)
  - Magma oceans on other planets
  - Atmospheres Pt. 1

Magma Oceans on Other Planets

- Gravitational potential energy larger for big planets
  so magma oceans more likely (for same accretion time scale)

- Earth will produce a blanketing atmosphere – keep it even hotter
  - Equilibrium between steam atmosphere and H_2O dissolved in rock may determine amount of H_2O left for ocean
  - Planetary thermostat might keep just enough H_2O in atmosphere for greenhouse to keep surface molten
    - If too little H_2O surface freezes, new incoming H_2O trapped in atmosphere
    - If too much H_2O surface melts and additional H_2O dissolves in magma ocean

- Differences
  - Reducing environment on moon changes chemistry
    - Sr^{+2} more common than Sr^{+3}
    - Fe^{+2} more common than Fe^{+3}
    - Eu^{+2} more common than Eu^{+3}
  - Lack of water makes anorthosite float on moon
  - Lack of blanketing atmosphere makes it form crust quickly on outside
  - Greater depth and gravity means higher pressure -- different minerals stable



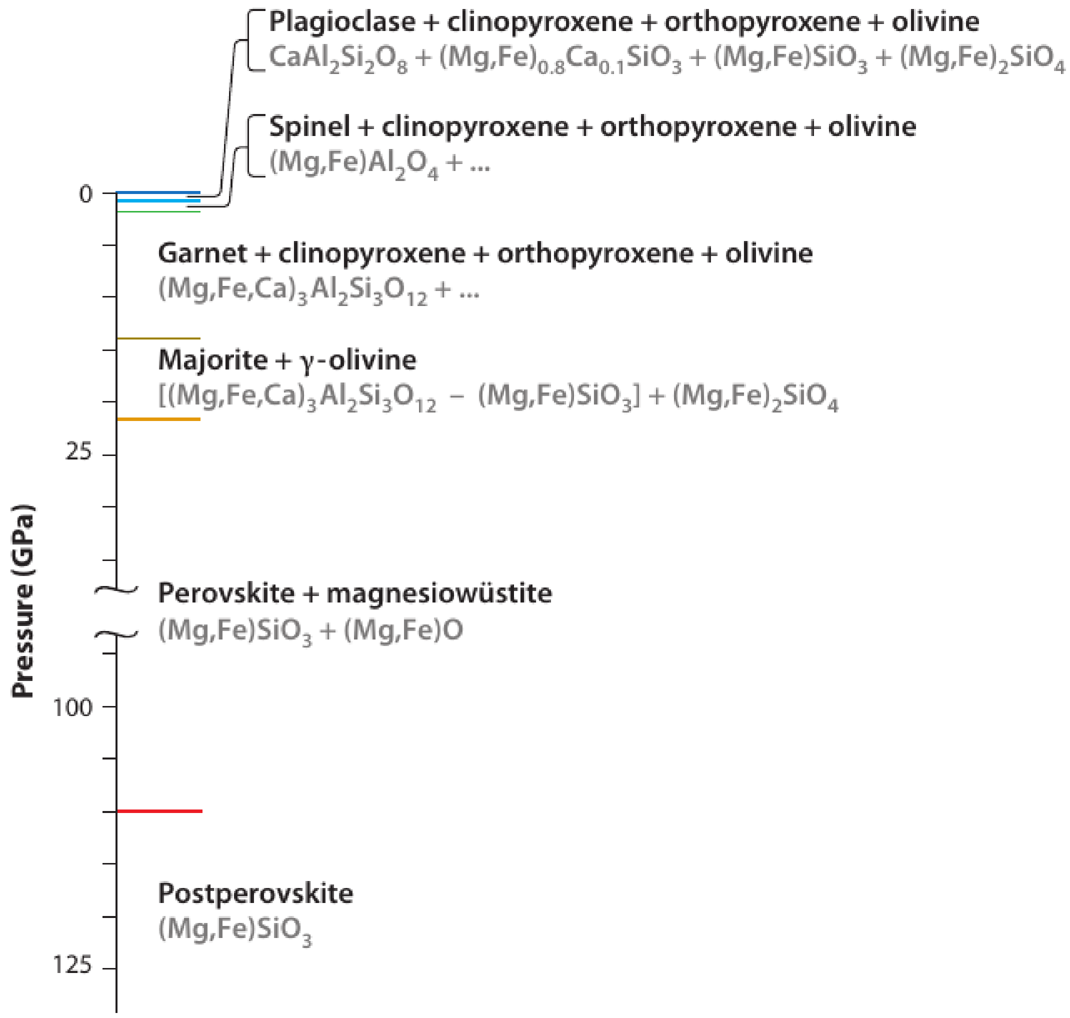
Early Earth History

Valley et al 2002

What is age of oldest surviving terrestrial crust?

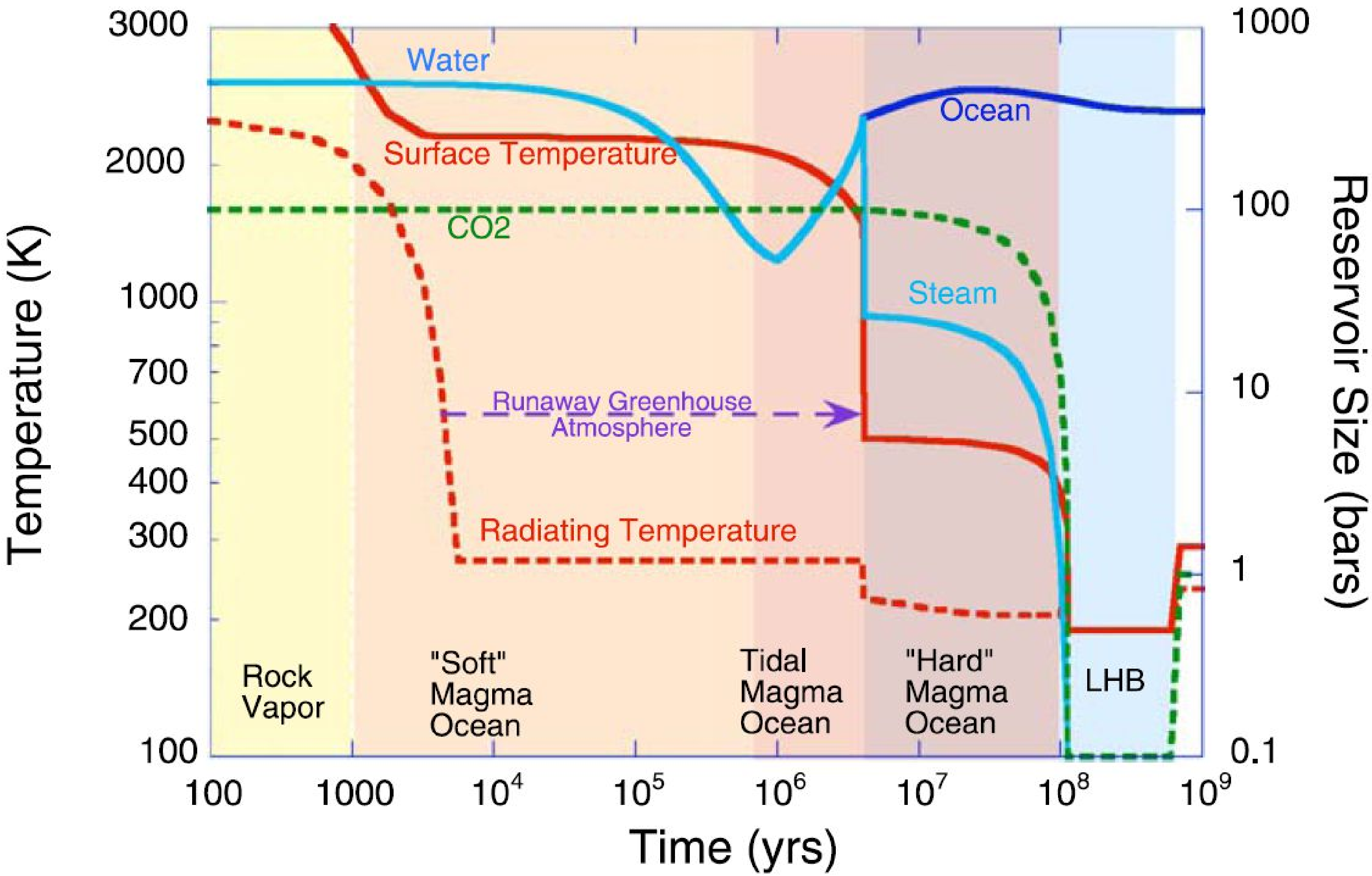
- Cooling rate – magma ocean?
- H_2O state?
- Late Heavy Bombardment

Minerals in Magma Oceans



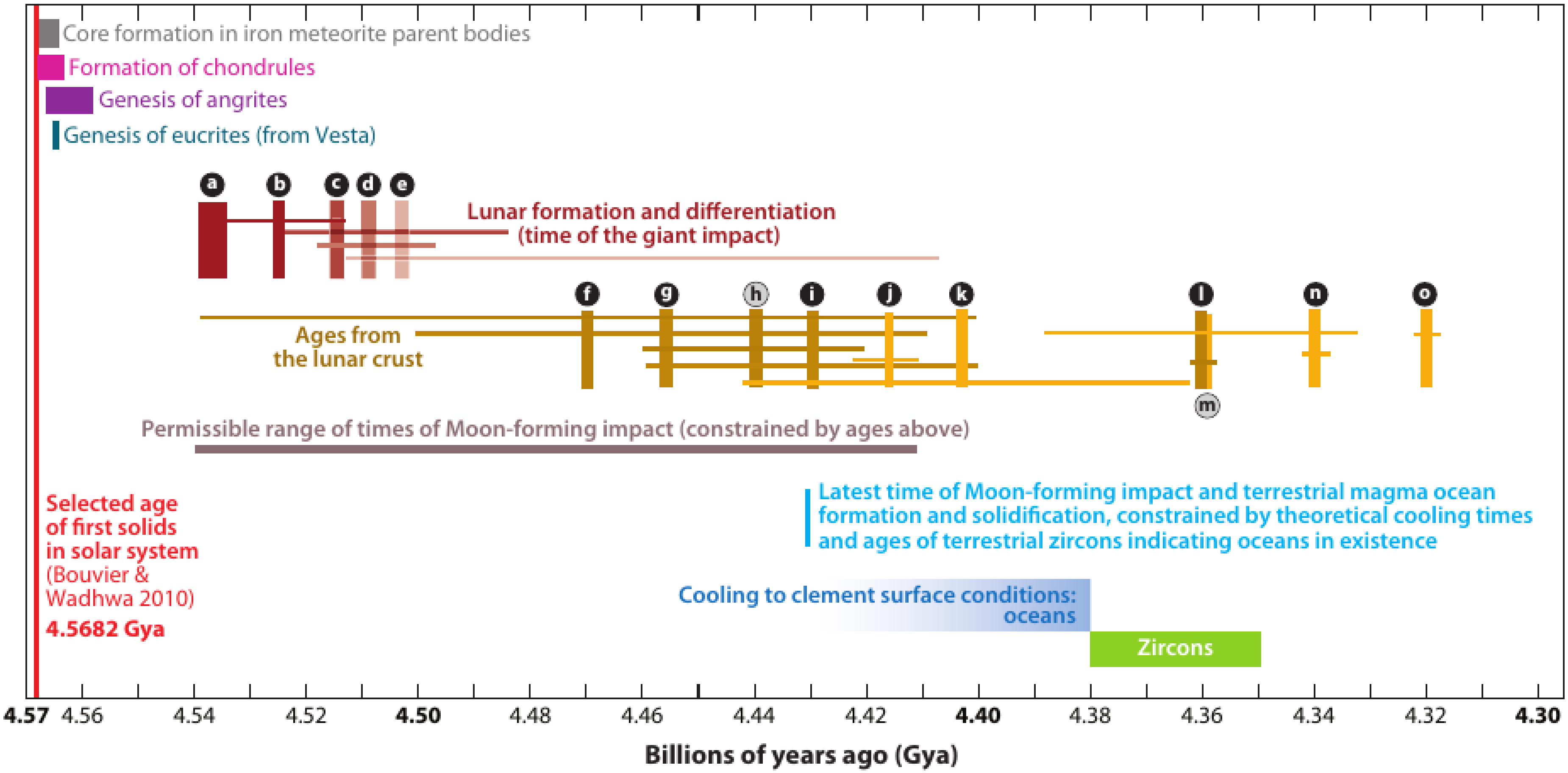
- From Elkins-Tanton "Magma Oceans in the inner Solar System" 2012 Ann. Rev. of Earth & Planetary Science 40: 113-139

Early Earth History



From Zahnle 2007

Early Earth System History



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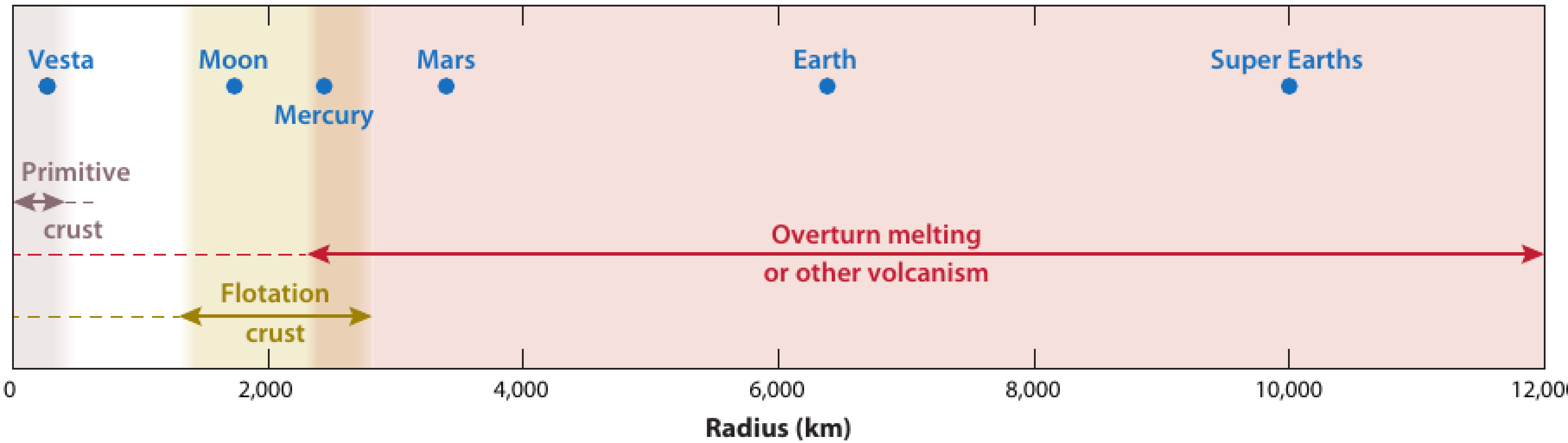
Different "primary" crusts from different magma oceans?



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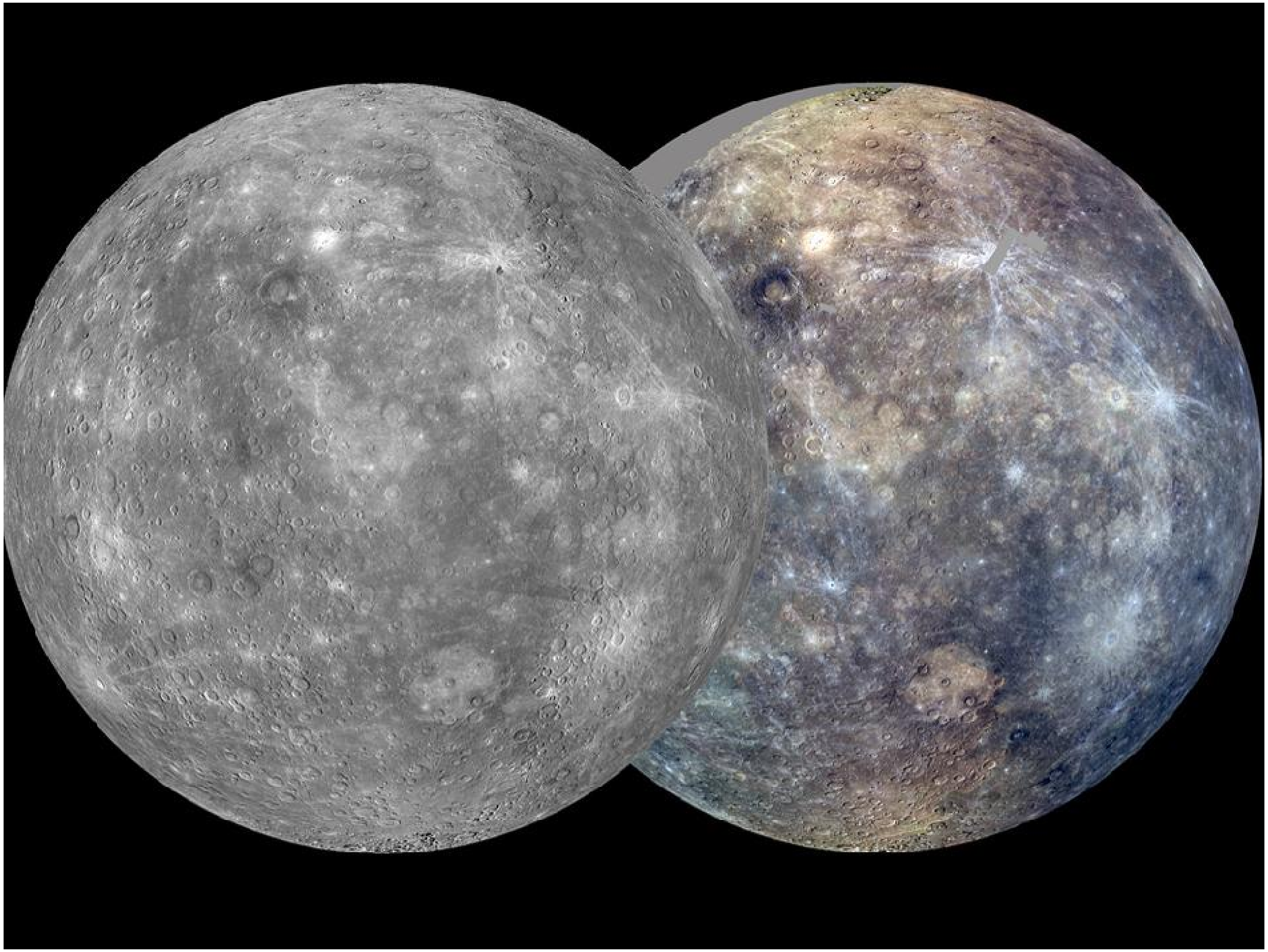
Mercury Results

- Mariner 10 flybys in 1974 - 1975
- Messenger flyby's over past few years, entering Mercury orbit in March 2011



Mercury Results

- Messenger observations from X-ray Spectrometry (Nittler et al. 2011, in recent special Science issue) indicate lack of anorthosite rich crust:
  - Lower Ca/Si and Al/Si ratios than terrestrial and lunar crusts
  - Higher Mg/Si ratio than terrestrial and lunar crusts
  - Intermediate between typical basaltic and ultramafic composition so similar to komatiites
  - Abundant sulfur so not a general lack of volatiles
- If FeO abundance in melt is too low anorthosite will not float (consistent with low FeO seen in the surface material)
- Density does show it has a large Fe core so Fe itself is not rare in Mercury's BULK composition, just FeO rare.
- Perhaps a more reducing environment means more of the Fe is concentrated in the core rather than in the mantle?

Vesta: from Eucrite meteorite composition

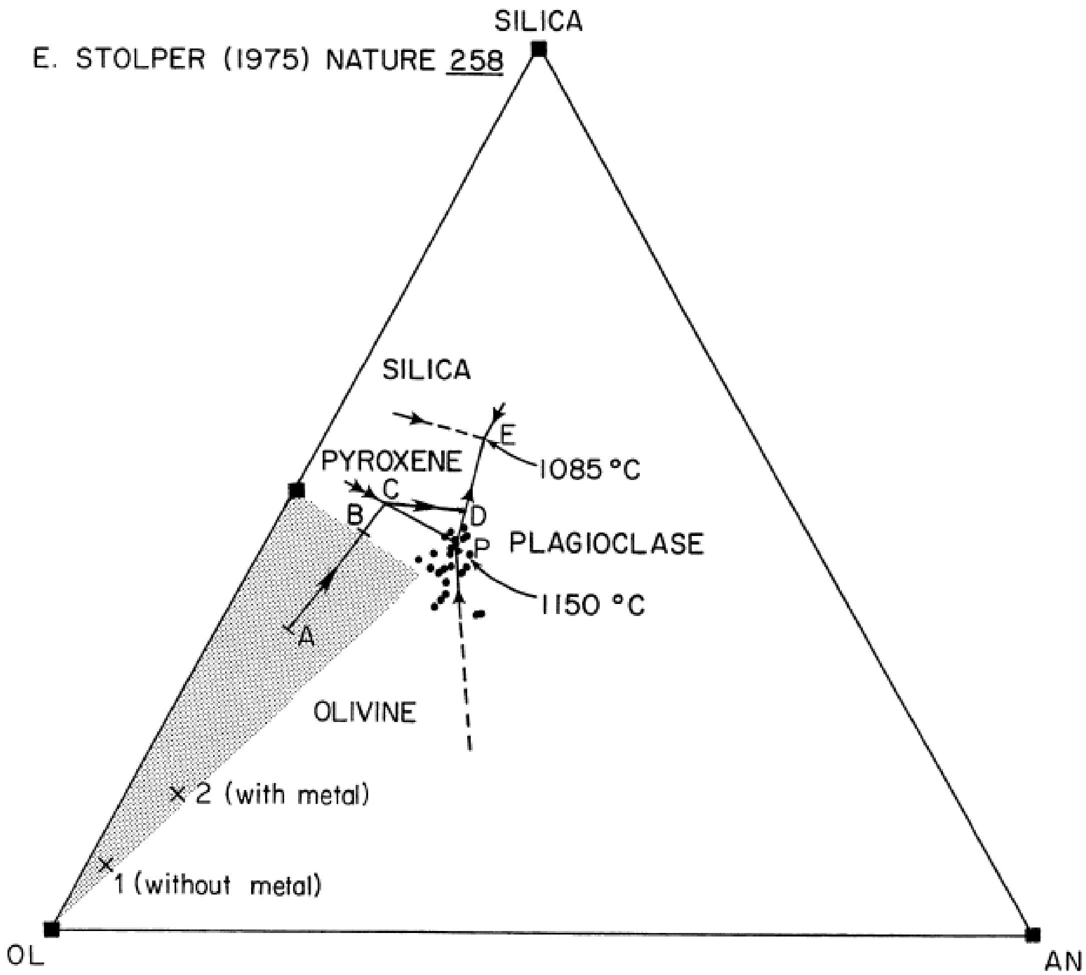


FIG. 4. Olivine–plagioclase–silica pseudoternary phase diagram for the eucrites. Average solar system material plots in the shaded area. Were a magma ocean to be generated by partially melting a composition such as "1" or "2", such that the magma ocean had composition "A", upon losing heat, it would evolve in composition under conditions of fractional crystallization by crystallizing olivine from "A" to "C", pyroxene from "C" to "D", and pyroxene and plagioclase from "D" to "E", the pseudo-eutectic point. The path under conditions of equilibrium crystallization would be "A"–"C"–"P". Note that the solid symbols are eucrites. That they cluster around the pseudo-peritectic point "P" is consistent with either equilibrium crystallization of a magma ocean in the shaded region towards olivine from the line connecting "PYROXENE", point "B", and "AN", or equilibrium partial melting of a bulk composition in that same region. After Stolper (1975, 1977).

- Crystallization at P suggest equilibrium crystallization (or melting), without isolation of solid fraction

- Old convection models suggested equilibrium not possible in magma ocean (crystals don't stay suspended)

Vesta REE Abundances & Europium Anomaly

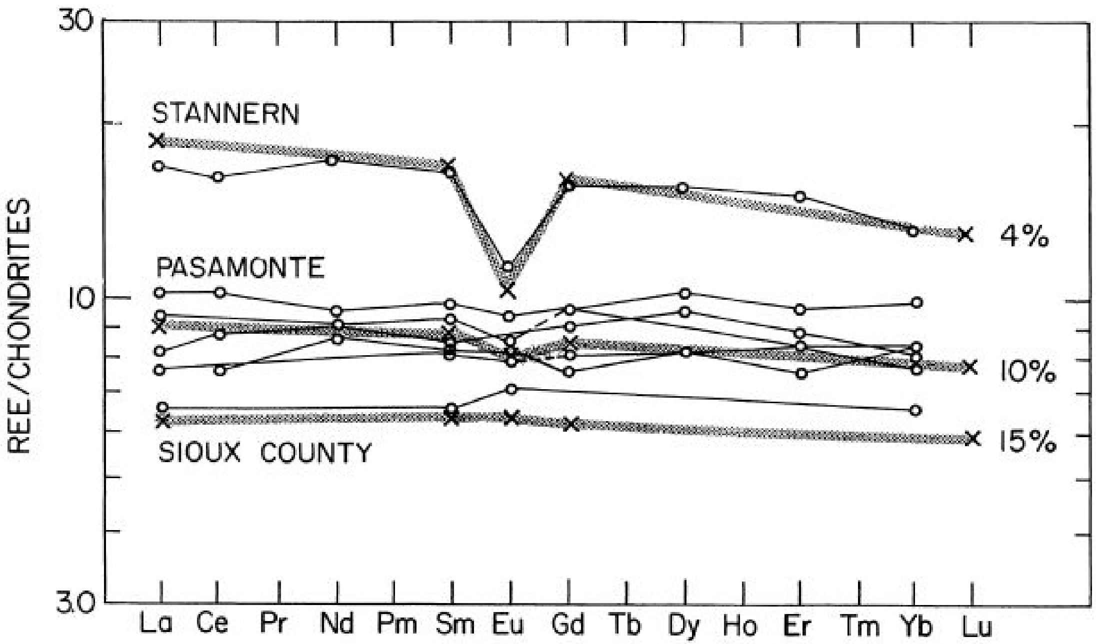


FIG. 5. Geochemical modeling of rare earth elements in eucrites showing that eucrites may be produced by equilibrium partial melting (or, equivalently, equilibrium crystallization) of average solar system material. Meteorite data are open circles connected by solid lines, model fits are "×" connected by thick shaded lines. 4%, 10%, and 15% refer to percent of equilibrium partial melting or equivalently, percent of melt remaining in an equilibrium crystallization process. After Consolmagno and Drake (1977).

- To match factor of ~10 enrichment in REE's, these eucrites must represent final 10% liquid in crystallization (or 10% partial melt of body)
- Partial melt initially favored based on inability to keep crystals in equilibrium in magma ocean (using OLD models)

Planetary Atmospheres

- Atmosphere slides moved to Mon. Oct. 30 lecture slides