1

BACKGROUND A - INITIAL CONDITIONS

- Because EARTH is strongly differentiated, we rely on meteorites for lots of information
- Many different classes of meteorites - which is most like Earth?

~~Achondrites~~
~~Chondrites~~
~~Irons~~

CHONDRITES
- Carbonaceous
  - CI
  - CM
  - CV
  - CO
- ordinary
  - H (high iron)
  - L (low iron)
  - LL (low iron, metal)
- Enstatite
  - EH (high iron)
  - EL (low iron)

Achondrites
- EHD
  - eucrites
  - howardites
  - diogenites
- SNC (MARS)
  - shergottites
  - Nakhlites
  - Chassignites

Irons
- Ataxites
- Hexahedrites
- Octahedrites

- Most meteorites are a mixture of mass dependent fractionated oxygen, and a ^{16}O-enriched CAI component
- Earth + moon are on the same mass-dependent line
- Mars is +0.3‰ above Earth-Moon Line
- CI's are ~+0.5‰ above Earth
- Enstatite chondrites are the only meteorite class on the Earth-moon line

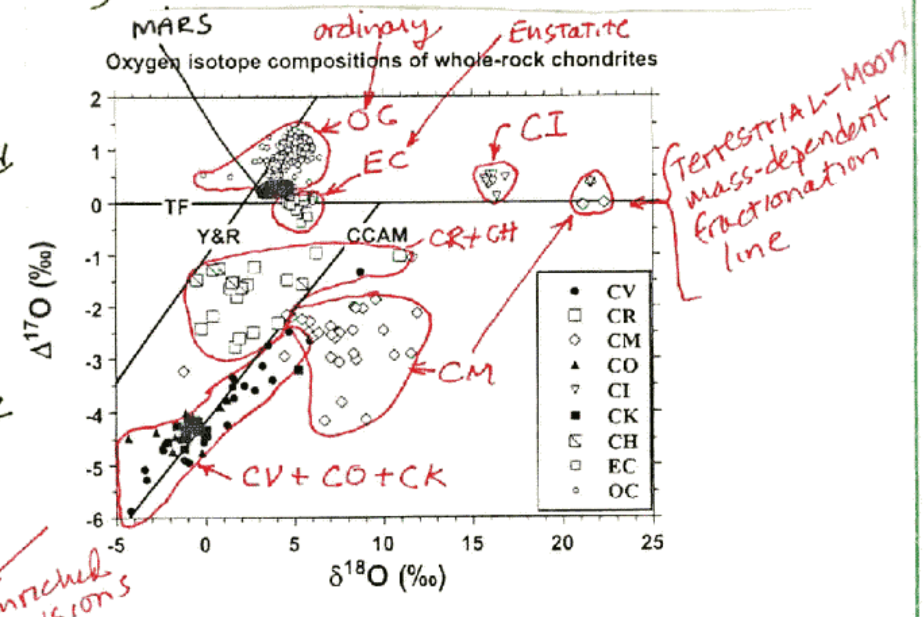
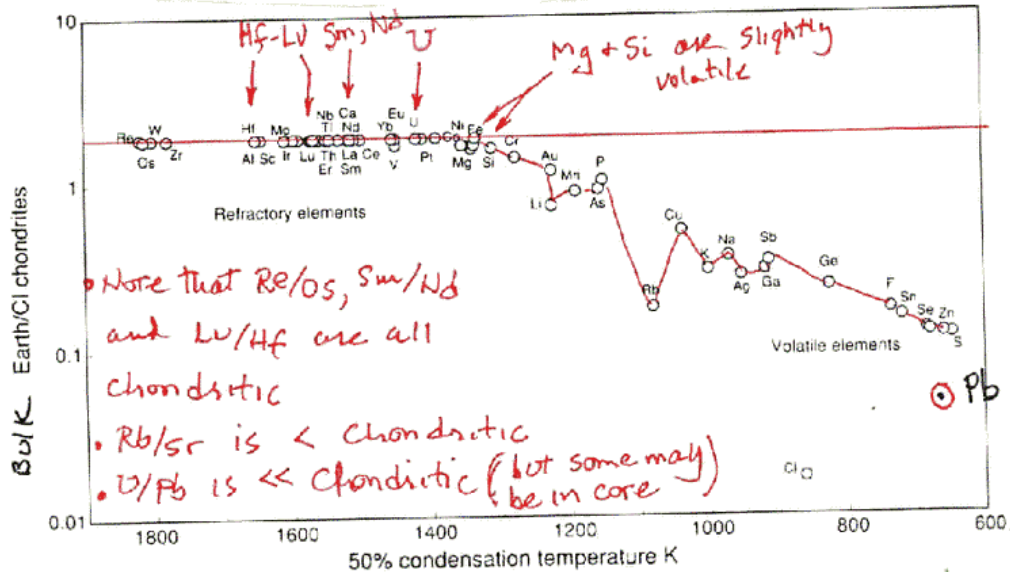


Figure 9. Oxygen isotopic composition of whole-rock chondrites according to group. Plotted are $\Delta^{17}O$ vs. $\delta^{18}O$ obtained by the BrF_5 method; most data are obtained in the laboratory of R. Clayton (data sources: ...

Condensation/Volatility in Planetary Bodies

- Solar abundances and CI abundances are very similar (except H and He). Suggests CI's are primitive solar condensates
- Other carbonaceous chondrites are devolatilized relative to CI's.



- Most "refractory" elements (condensation T's > 1300°K) have same relative abundances in Earth and CI's
- absolute conc's are higher in Earth because CI's have more volatiles:
  - 30% of CI's is H_2O, C, N, S and organics
- of course, some of this is circular, because we have used some meteorite "information" to derive Earth composition
- To first order,

  Silicate Earth = CI − 30% volatiles
  − 32.5% Fe-Ni-O metallic core

* Mg/Si – Al/Si plot – meteorites vs peridotites

AGES OF SOLAR MATERIAL

		Pb-Pb
CHONDRITES	Allende Ca-Al rich inclusions	4567 ± 0.6 my (2002) / 4566 ± 8 my
	Ordinary chondrites (Ste. Marguerite)	4563 ± 1
	angrites (Angra dos Reis)	4558 ± 3
Achondrites → Eucrites	(Ibitara)	4560 ± 3

The oldest Sm/Nd age with good precision is the eucrites: EET 87520 − 4547 ± 9
+ Caldera − 4544 ± 19

(no precise Sm/Nd ages on chondrites!)

Lunar – lunar anorthosites { Sm/Nd = 4560 ± 70 my; Pb-Pb ~ 4510 ± 10 my }

Earth – no "direct" ages, as all known earth materials have been "processed", and no "single-stage" materials exist.

– given that accretion of meteorites started at 4567 (CAI's), followed quickly by chondrites (4563), and then differentiated materials (achondrites) at 4560, suggests earth probably also formed in this time interval (4567 → 4560 my). This is a conjecture!

– Since we believe the moon was formed from the earth by giant impact, then the earth is ≥ age of the moon ≥ 4510 m.y.

Constraint from Hf-W

$$^{182}Hf \rightarrow {}^{182}W \; ; \; t_{1/2} = 9 \text{ m.y.}$$

- since the parent Hf is lithophile + the daughter W is siderophile, core formation will deplete silicate mantle in W, leading to high Hf/W, and high $^{182}W/^{184}W$ if core formation occurs before ^{182}Hf has all decayed.

- reference for $\epsilon_W \equiv 0$ is all earth materials

	ϵ_W
Iron meteorites →	-3 – 5
Carbonaceous Chondrites →	-1.9
H-chondrites	-3.3
E-chondrites	-2.2
Martian Meteorites	+0.5
Eucrites (= Vesta) (520 km dia)	+14 to +27
Earth	≡ 0

{ due to high Hf/W ~ 30, versus ~1.5 for Carbonaceous Chondrites (Earth ~ 10) }

- If core formation on earth took place long after ^{182}Hf was "dead", Earth + Chondrite would have same $^{182}/^{184}W$

(4.)

Hf-W
CORE FORMATION Ages

- Relative to absolute Age of CAI's (from Pb-Pb) = 4567 my
- Larger bodies appear to have a longer "growth" period before core formation occurs.

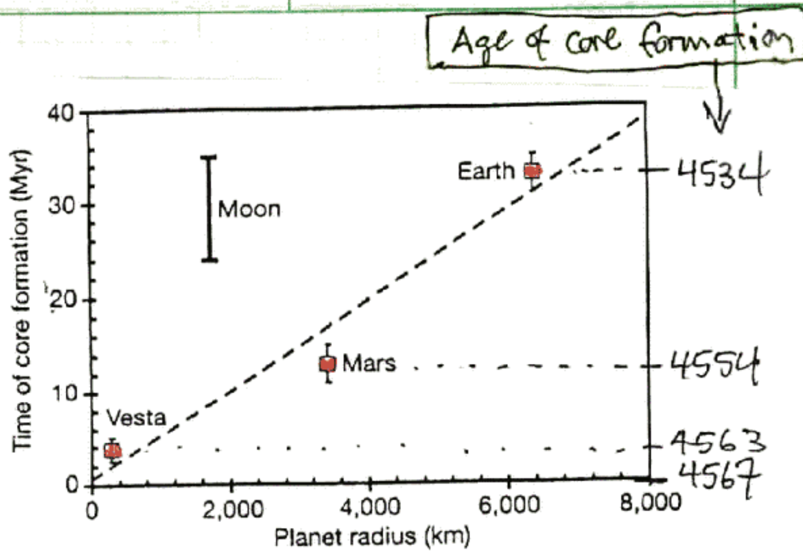


Figure 3 Time of core formation in Myr after CAI condensation for Vesta, Mars, Earth and Moon versus planet radius as deduced from Hf–W systematics. For the Moon, the two data points refer to the endmember model ages.

$^{146}Sm - ^{142}Nd$ Mantle Differentiation Ages

$^{146}Sm \rightarrow ^{142}Nd$; $t_{1/2} = 103$ my

- Seven samples of metasediment from ISUA greenstone belt, Greenland, have small ^{142}Nd anomalies (15 ± 4 ppm)
- "mean" age of mantle differentiation: ~4460 ± 115 my

This is ~ 75 my after core formation

OLDEST TERRESTRIAL ROCKS

Acasta Gneiss – Slave Craton — 3.96 by (tonalitic to granitic orthogneisses, amphibolites)

OTHER OLD ROCKS – Antarctica – orthogneisses – 3.87 by
Labrador – gneisses – 3.86 by
Greenland – gneisses – 3.82 by

Greenland – quartzite, detrital zircon – 3.88 by

Australia – quartzite, detrital zircon – 4.40 by (ion probe single spot in a single grain of zircon with heterogeneous ages)

(5)

ANY PRIMORDIAL MATERIAL LEFT?

Pb isotope constraints:

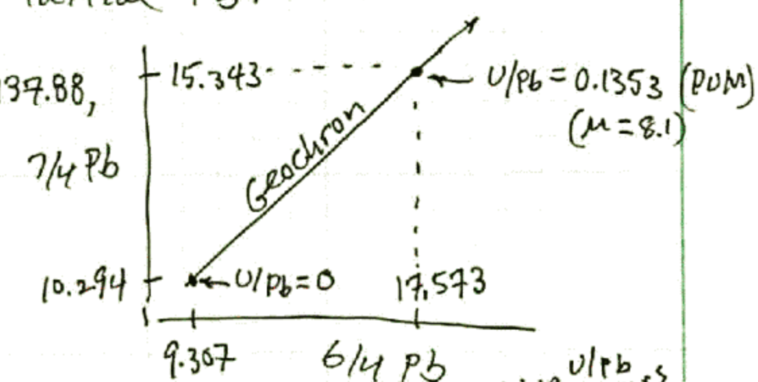
primordial Pb (Canyon Diablo troilite) (no U, just Pb)

[6/4 = 9.307
7/4 = 10.294
8/4 = 29.476]

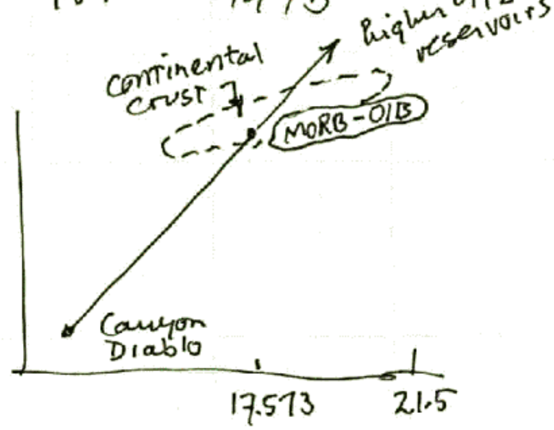
[$^{235}U \rightarrow 207Pb$
$^{238}U \rightarrow 206Pb$
$^{232}Th \rightarrow 208Pb$
204Pb = stable isotope]

[U/Pb of C1's = 0.00283
U/Pb of upper mantle = 0.1353] > factor of 47.8

- so Pb "age" basically dates the time when U/Pb of silicate earth "increased"
  { Pb into core
  Pb volatilization }
- using core formation age (from Hf-W) of 4534 my and Canyon Diablo initial Pb:
- because $\frac{^{238}U}{^{235}U}$ is fixed, = 137.88, slope on this plot is function only of halflives of 235 + 238, and elapsed time



- any "primordial" earth material must lie on this Geochron
- very little Pb lies on Geochron (except in odd crustal rocks, and a few OIB, which don't have Bulk Earth Nd however)

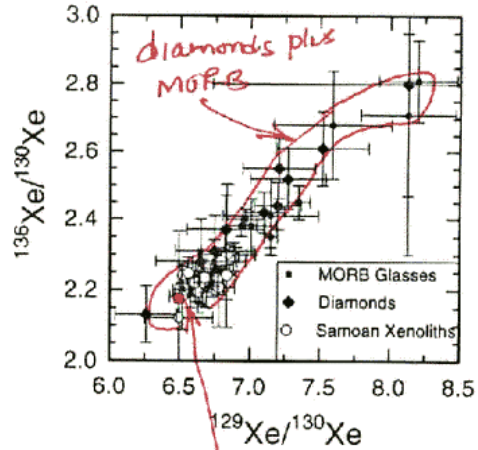


The story from ^{129}Xe

$^{129}I \rightarrow {}^{129}Xe$ $t_{1/2} \sim 17$ my

$^{244}Pu \rightarrow {}^{136}Xe$ $t_{1/2} \sim 80$ my { ^{136}Xe also produced by ^{238}U fission over all time

- ^{129}Xe and ^{136}Xe are ~ correlated
- MORB and diamonds are ≥ atmosphere
- Thus far, all OIB's are ~ atmospheric



- conclusion
  - Some MORBS and Diamonds have up to 25% excess of ^{129}Xe and ^{136}Xe.
  - Proves these "reservoirs" have been isolated from the atmosphere since ~ 50–100 my after accretion.

Earth atmosphere

- small ^{129}Xe excesses also in Samoa xenoliths

- atmosphere "could have" been introduced post-accretion and not well-mixed into mantle.
- OIB's may be locally contaminated with atmosphere.
- Although very important discovery, the measurements are extremely difficult and only a few labs even potentially capable!