Origin of the Universe

- **Big Bang Hypothesis: ~14 Billion Years back**

Origin of the Sun

4.6 billion years interstellar material aggregated to form cloudy mass, the solar nebula

Sun formed from gravitational collapse of solar nebula

Origin of the Earth

4.6 bya, rock-forming elements, which were gases at high temperature in solar nebula, condensed into small solid grains as nebula cooled.

Grains accreted to planetesimals, such as asteroids and comets.

Planetesimals accreted to form the Earth and other planets

The Planets

Inner Planets: Mercury, Venus, Earth, Mars

Characteristics: Lost much of the volatiles

Smaller in size

Rocky and metallic (Fe-Ni)

Outer Planets: Jupiter, Saturn, Uranus, Neptune

Characteristics: Larger

Icy

Gaseous

Asteroidal Belt between the Mars and Jupiter;
Meteorites ; intermediate in characteristics

Kuiper Belt- Comets

Giant Impact: After the formation of the Earth, a period of intense bombardment by asteroids happened

The Moon probably formed by Giant Impact

Age of the Earth

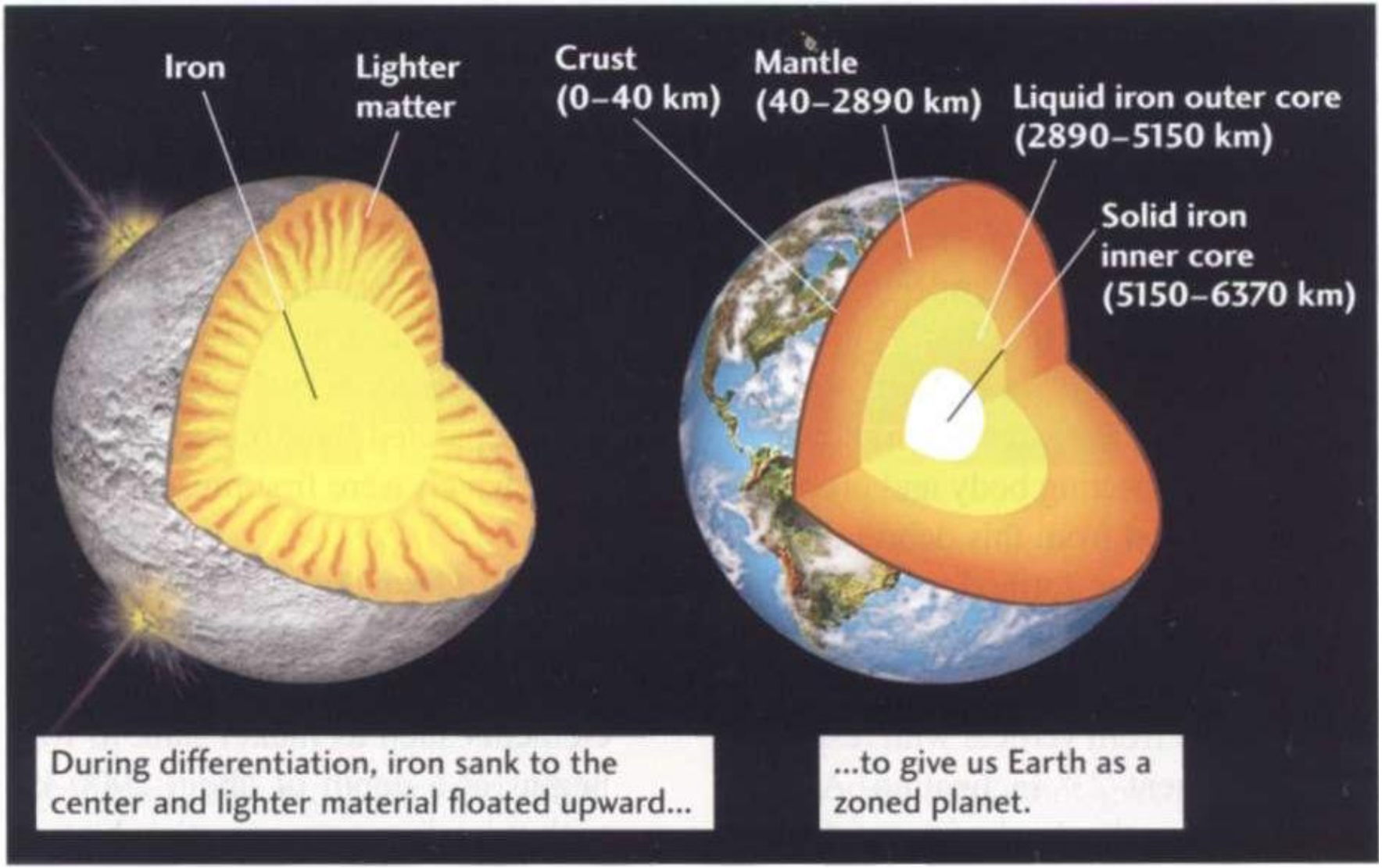
Bracketed by the age of the oldest known meteorite 4.56 b.y and the oldest Apollo Moon Rock 4.46 b.y as ~4.53 by

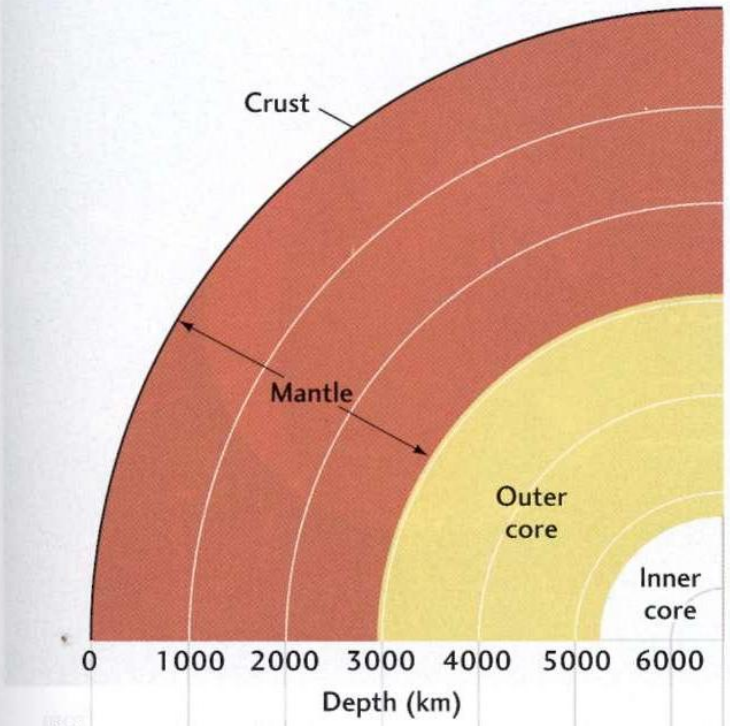
Due to Giant Impact and internal heating it is estimated that about 70% of the Earth got molten after its formation

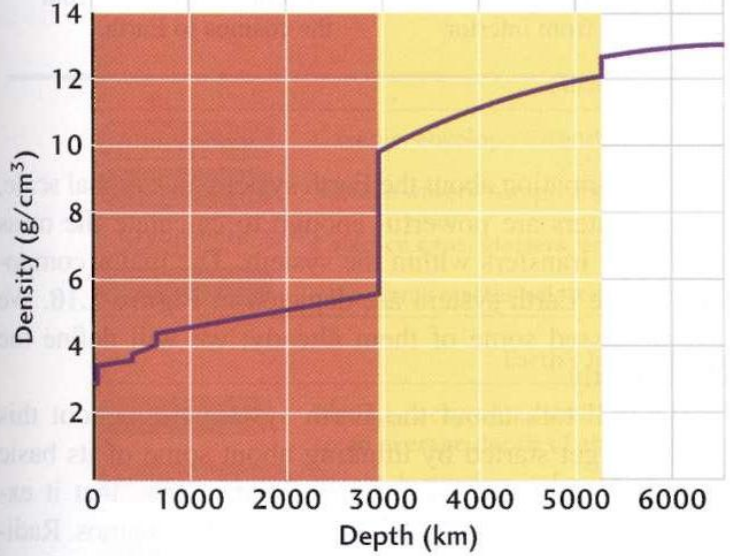
Differentiation produced core and mantle

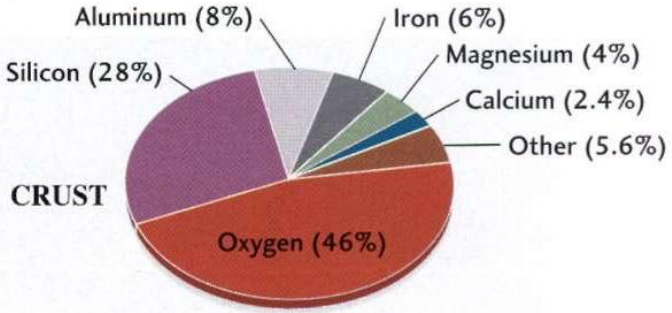
Further melting and differentiation of the Mantle produced the Crust

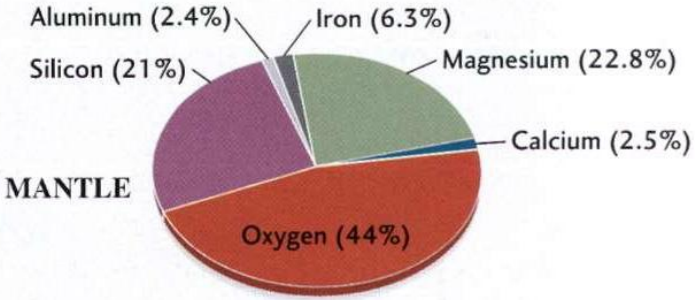
The Crust also formed very early as we have rocks in the crust as old as ~4.4 by

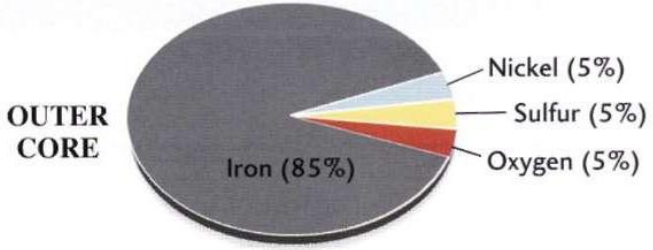

Iron
Lighter matter
Crust (0–40 km)
Mantle (40–2890 km)
Liquid iron outer core (2890–5150 km)
Solid iron inner core (5150–6370 km)
During differentiation, iron sank to the center and lighter material floated upward...
...to give us Earth as a zoned planet.

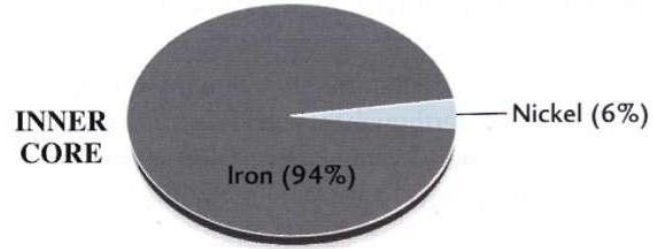

Crust
Mantle
Outer core
Inner core
0 1000 2000 3000 4000 5000 6000
Depth (km)


14
12
10
8
6
4
2
Density (g/cm³)
0 1000 2000 3000 4000 5000 6000
Depth (km)


Aluminum (8%)
Iron (6%)
Magnesium (4%)
Silicon (28%)
Calcium (2.4%)
Other (5.6%)
CRUST
Oxygen (46%)

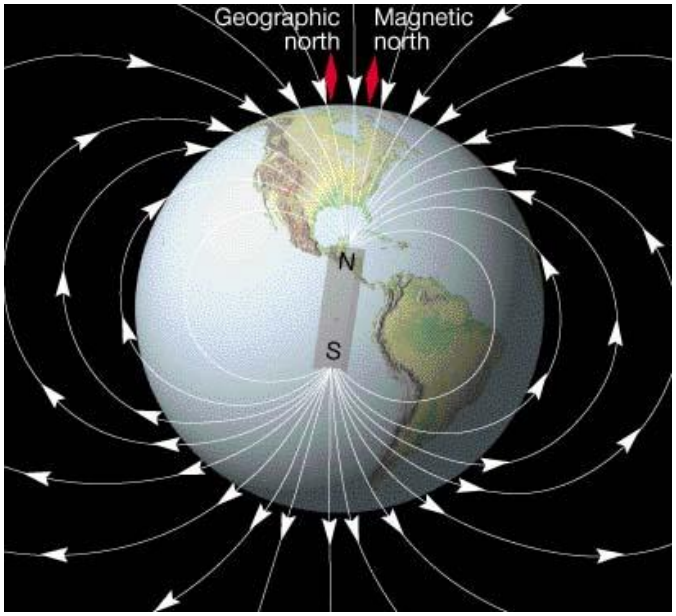

Aluminum (2.4%)
Iron (6.3%)
Silicon (21%)
Magnesium (22.8%)
Calcium (2.5%)
MANTLE
Oxygen (44%)

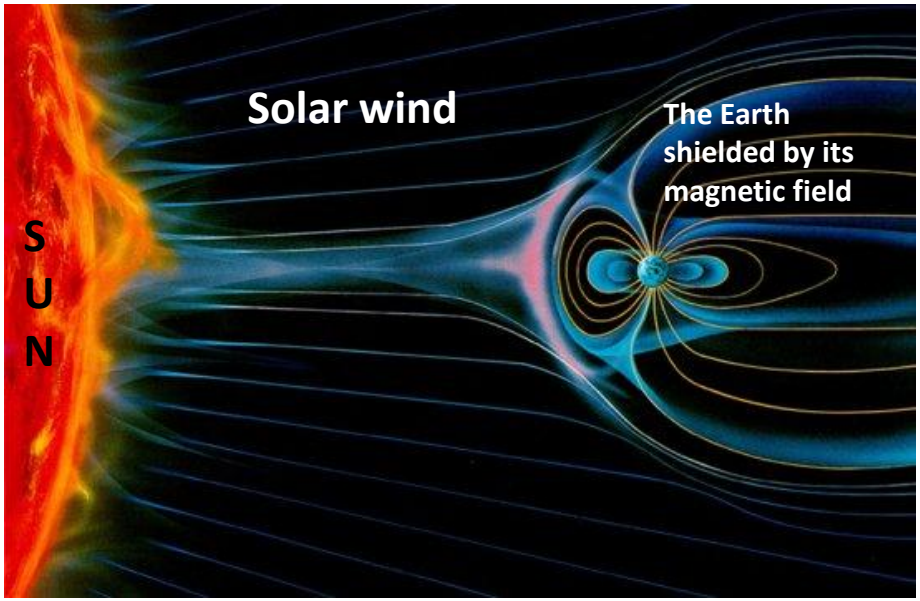

Nickel (5%)
OUTER CORE
Sulfur (5%)
Iron (85%)
Oxygen (5%)


INNER CORE
Nickel (6%)
Iron (94%)

Earth's magnetic field

- **Earth has a magnetic field. That's why you can use your compass.**
- **It works as a shield against harmful solar winds.**
- **As a result we still have atmosphere and Mars does not. Strong solar wind ripped the early Martian atmosphere.**





How was the magnetic field created?

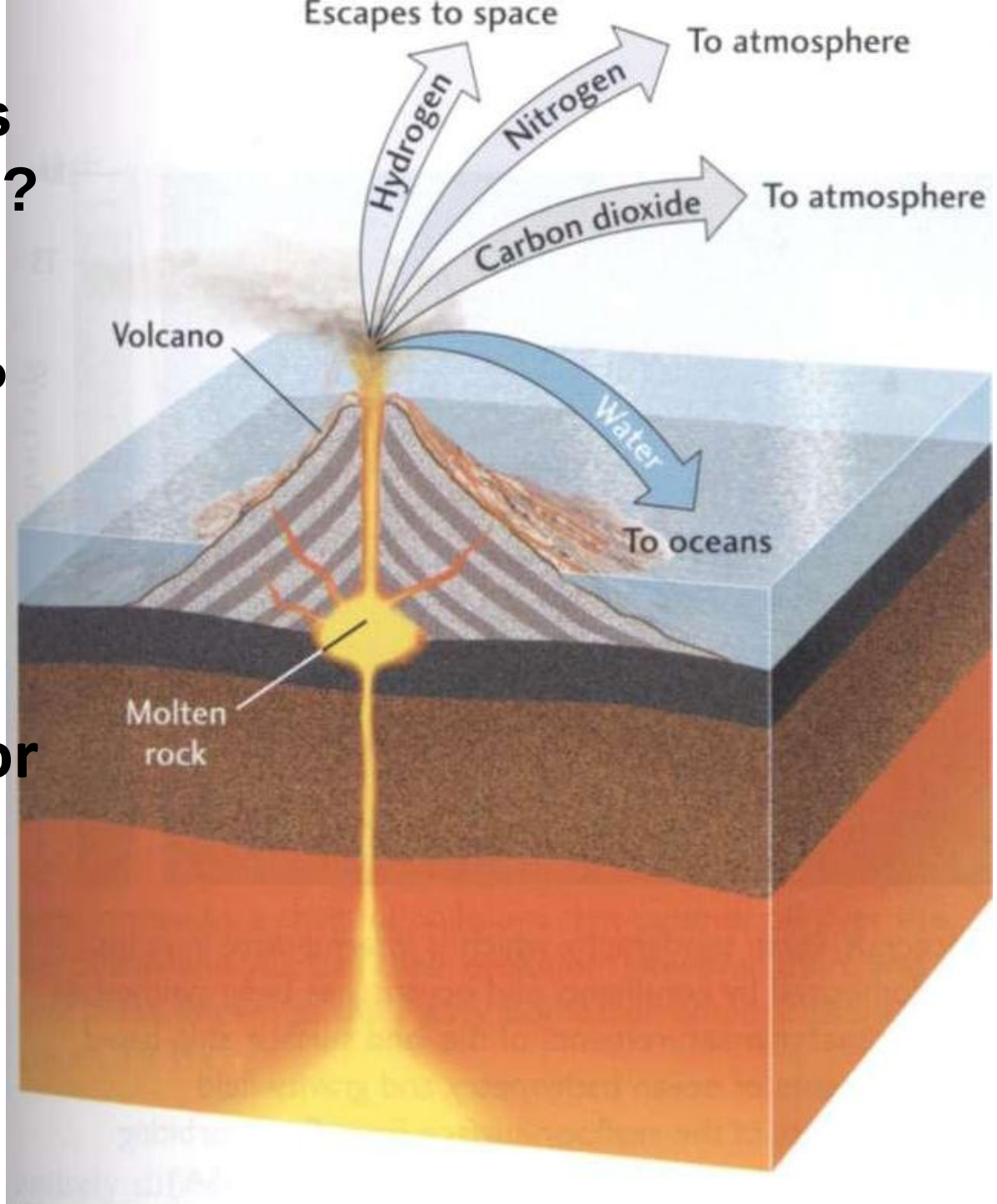
How was the Earth's Atmosphere formed?

External or Internal ?

External: Comets?

Internal: Degassing of the Earth's interior through volcanism

Clue from present volcanoes



Solar Abundance of elements

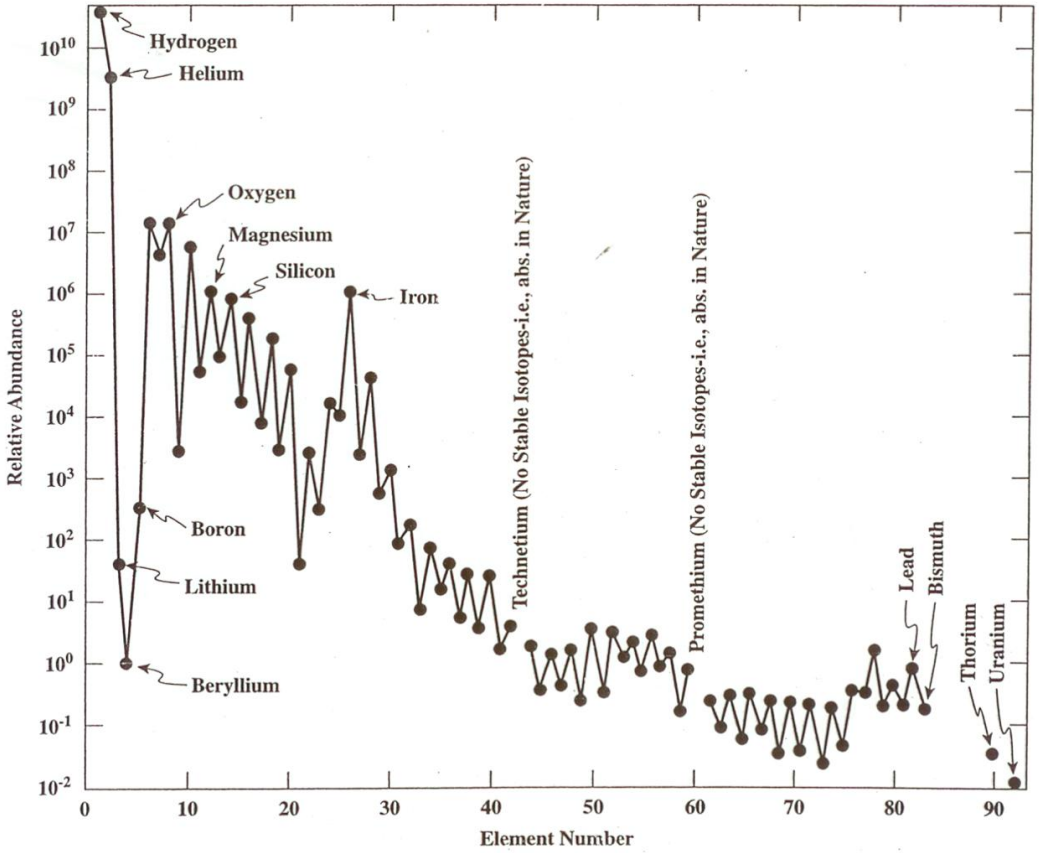


Figure 3.8. Primordial solar system abundances of the elements, derived from values in the Sun and primitive meteorites (see chapter 5). Abundances are plotted on a *logarithmic* scale, so that each tick mark on the vertical axis means an increase or decrease by a factor of 10. Reproduced by permission from Broecker (1985).

Solar Abundance of elements

Relation with mass number

a) Rapid exponential decrease for elements 1-40

b) Pronounced peak for Fe26

c) Even atomic number more common than odd numbers on both sides

d) 10 elements with atomic number <27 are most abundant: H, He, C,N,O Ne,Mg,Si,S,Fe

Nucleii with even N + even Z most abundant

Nucleii with odd N-even Z & even N-odd Z are equally abundant

Nucleii with odd N and odd Z least abundant- exception N(14)

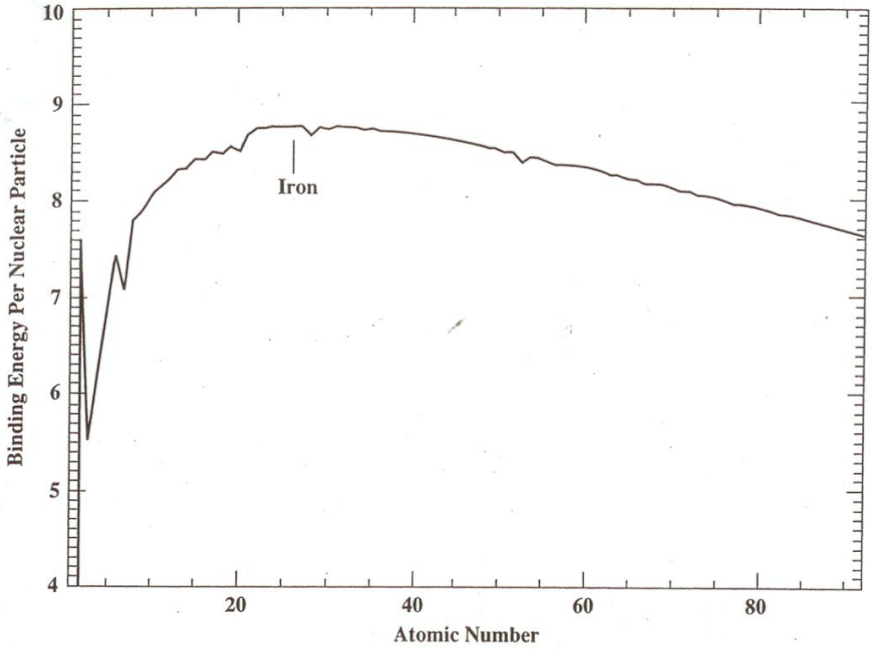
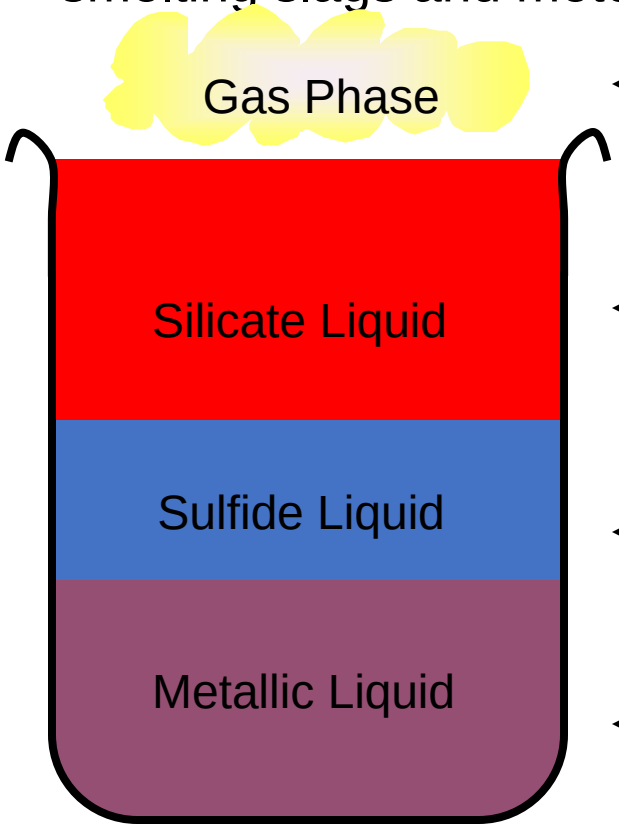


Figure 4.1. Binding energy of the nucleus as a function of atomic number. The higher the energy, the more stable is the nucleus against fragmentation or other decay. Note that stability is highest around the atomic number corresponding to iron. The binding energy is expressed relative to the number of protons and neutrons in the nucleus, and the units are millions of *electron volts*. One electron volt is 1.6×10^{-19} joules, and is a convenient unit for energies on the small scale of atoms. The curve was computed from a model that roughly fits the measured value for most elements, but there are small deviations from the experimental values.

Geochemical Affinity

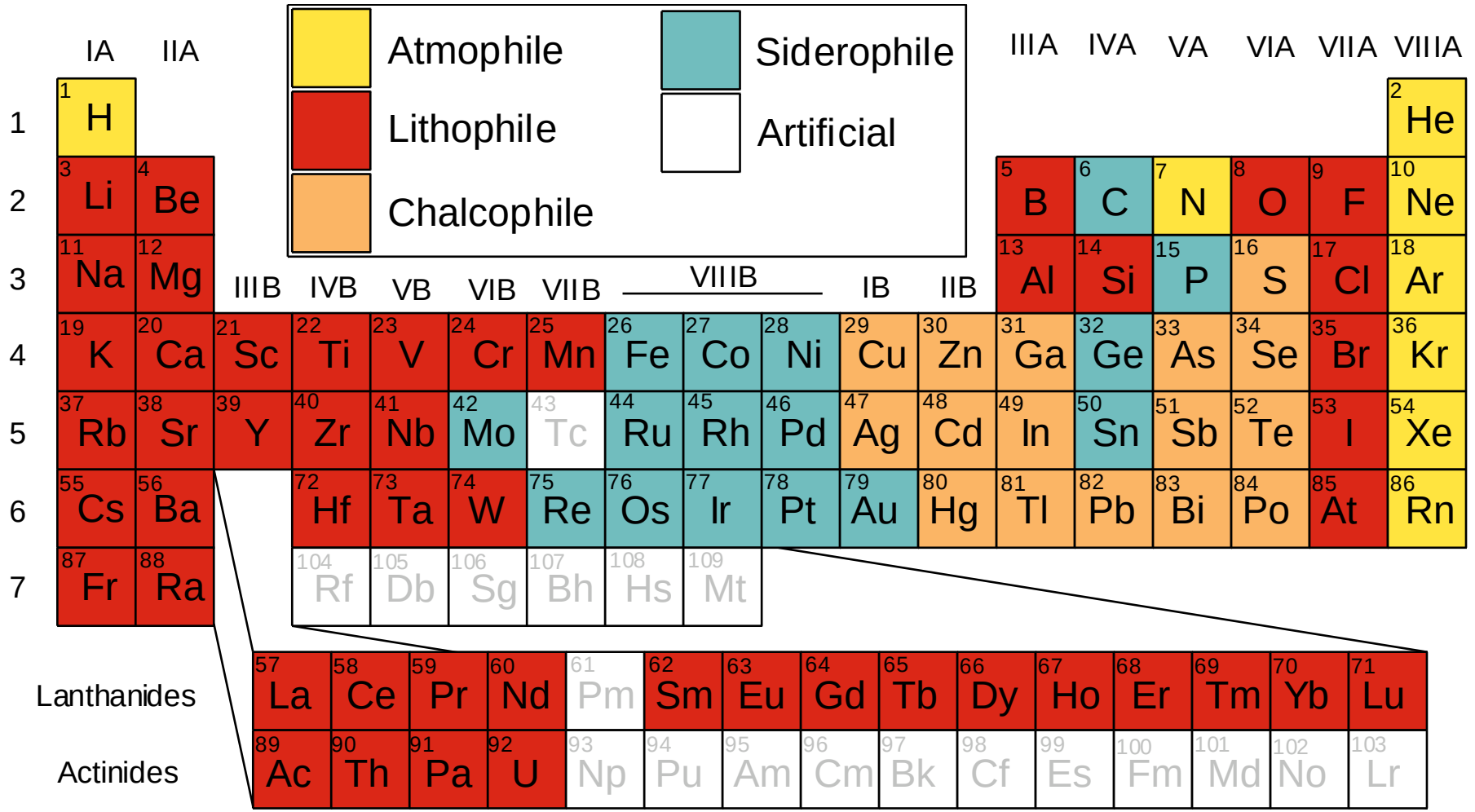
- In the classification scheme of Goldschmidt, elements are divided according to how they partition between coexisting silicate liquid, sulfide liquid, metallic liquid, and gas phase…defined by examining ore smelting slags and meteorites



← Atmophile	H, He, N, Noble gases
← Lithophile	Alkalis, Alkaline Earths, Halogens, B, O, Al, Si, Sc, Ti, V, Cr, Mn, Y, Zr, Nb, Lanthanides, Hf, Ta, Th, U
← Chalcophile	Cu, Zn, Ga, Ag, Cd, In, Hg, Tl, As, S, Sb, Se, Pb, Bi, Te
← Siderophile	Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, Pt, Mo, Re, Au, C, P, Ge, Sn

Geochemical classification of elements

What makes an element siderophile or lithophile? Notably, the Goldschmidt categories are well-grouped in the **periodic table of the elements**:



Meteorites

Meteoroid enters the atmosphere and burns to produce **meteor.**

Meteor falling on the Earth is **Meteorite**

Classification: IRONS (6%), STONY IRONS (2%) and STONES (92%)

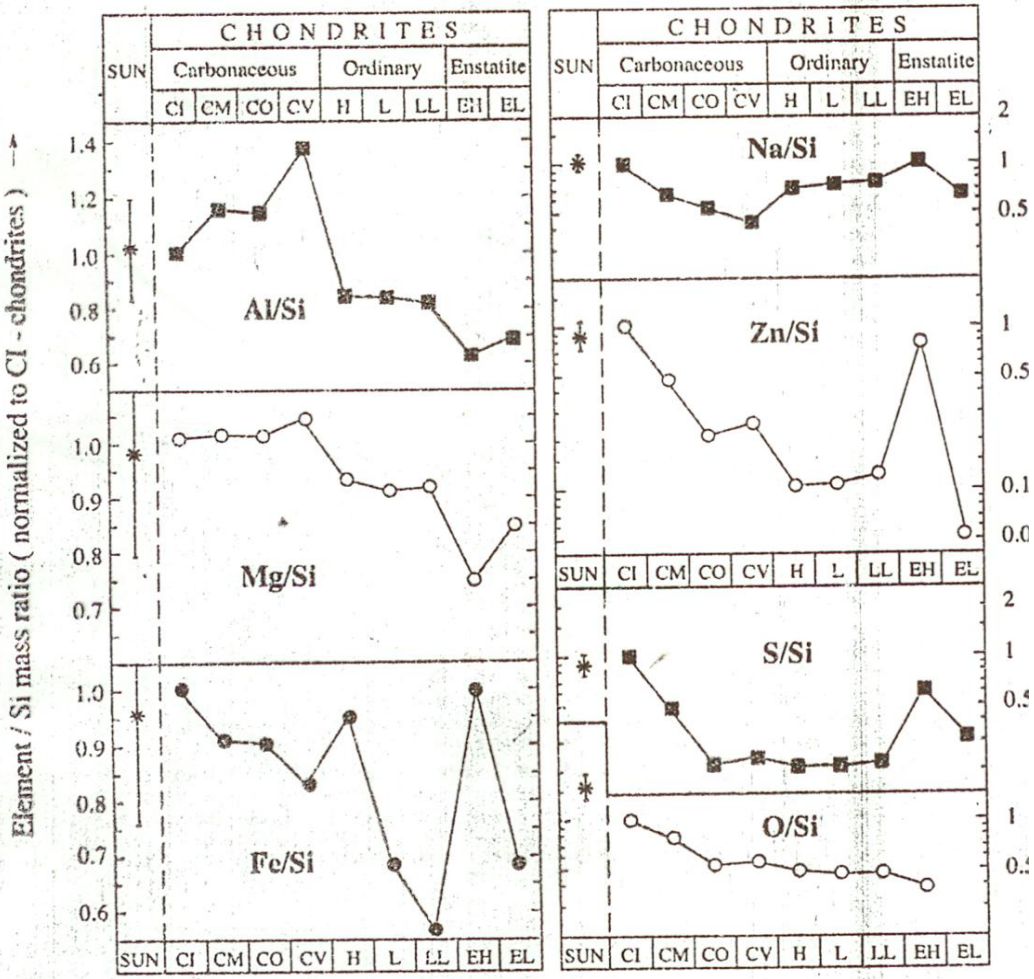
STONES are further divided into Chondrite (84%) and Achondrite (8%)

Basis: Chemistry, Mineralogy, Microstructure

IRONS: Fe-Ni Alloy + FeS (very similar to the core of the Earth)
STONY IRONS: Fe-Ni Alloy + Fe-Mg silicates
STONES: Basically Fe-Mg silicates; Chondrites are with **Chondrules**
A special type of Chondrite is Carbonaceous Chondrite with C, minerals with water And other volatiles

Carbonaceous chondrites are further subdivided, but Type I is considered to be most primitive as it contains maximum volatile matter.

Fig. 1


CHONDRITES
SUN
Carbonaceous
Ordinary
Enstatite
CI CM CO CV H L LL EH EL
Al/Si
Mg/Si
Fe/Si
Na/Si
Zn/Si
S/Si
O/Si
Element / Si mass ratio (normalized to CI - chondrites)

Cosmochemical classification of elements

Basis: Condensation temperature

Tc is calculated at 10x-4 bars

Refractory: Al, Ti, REE, U, Pb… 1400-1850K
Main Component: Mg,Cr,Si….1250-1350K
Moderately volatile: Mn,P, Rb,K…640-1230K
Highly volatile: Cl,Br,H,C,O….<640K

Cosmochemical classification of elements