Week 2 Lecture 1: Origin of Earth and Oceans

Chemical reservoirs resulting from chemical differentiation: major elements (and minor elements):

Sun: H, He
Earth: Fe, O, Si, Mg (Ni, Ca, S, Al)
Oceans: H, O (Cl, Na, Mg, S, Ca, K)
Atmosphere: N, O (Ar, H_2O, CO_2)
Life: H_2O, C (N, P)

With only a few exceptions, each of these reservoirs
is made up of a ***different*** set of elements.
This implies **CHEMICAL DIFFERENTIATION**.

CHEMICAL DIFFERENTIATION:
--large-scale separation of chemical elements
on the basis of their physical and chemical properties,
by a variety of processes

Solar System:
Sun
Inner rocky planets
(Mercury, Venus, Earth, Mars, asteroid belt)
Outer gas-giant planets
(Jupiter, Saturn)
Outer ice-giant planets
(Uranus, Neptune)

Earth:
*Core of iron
*Mantle and crust of rock
Oceans
Atmosphere
(*How do we know? Meteorites, bulk density, seismic waves, sampling)

Our Solar System:
Inner ***rocky*** planets: Mercury, Venus, Earth, Mars, asteroid belt
Outer ***gas-giants***: Jupiter, Saturn
Outer ***ice-giants***: Uranus, Neptune
(Pluto is rocky and about the size of Earth's Moon.
It was probably captured from outside the Solar System.)
The inner rocky planets lie close to the Sun.
Note the irregular orbit of Pluto, which makes it
sometimes the 9th planet and sometimes the 8th!

Bulk Composition of Earth

- **Fe** **36.0 wt%**
- **O** **28.7**

- **Si** **14.8**
- **Mg** **<u>13.6</u>**

  93.1
- **Ni** **2.0 wt%**
- **Ca** **1.7**
- **S** **1.7**
- **Al** **1.3**

Eight most abundant elements account for 98-99% of total Earth mass
***Sun*: 75% H and 23% He**

Star Formation
Gas in nebula aggregates forms a proto star.
Gravity compresses star until temperature ~ 10 million degrees.
Hydrogen fusion starts, forms chemical elements up to
carbon and oxygen, and up to iron in large stars.
Star shines for billions of years until most of hydrogen is used up.
Medium star then expands as heavier atoms fuse,
forming a ***Red Giant*** that finally cools and contracts
to become a ***White Dwarf***.
Our sun will do this in 5-6 billion years.

For a **larger star**:
As hydrogen runs out, starts to collapse, temperature goes up and then star explodes.
Supernova explosion lasts ~10 seconds. All elements heavier than iron are formed
in this way!

Summary of our Solar System
- By the time solar system spun and produced the current planetary arrangement, its composition was nearly final:
  - ➔ 75% Hydrogen
  - ➔ 23% Helium
  - ➔ 2% everything else…
- Central part of nebula, mostly H and He became our Sun.
- Material condensed on the periphery accreted gravitationally… but heat of sun affected its distribution.
- Rocky planets (***refractories***) formed closest to sun.
- Gas planets (***volatiles***) condensed furthest out.
- Asteroid belt (between Mars and Jupiter) is a failed planet.

CHEMICAL DIFFERENTIATION:

VOLATILE **ELEMENTS AND COMPOUNDS:**

--those that tend to form gases, even at relatively low temperature:
H, He, O, N, and the noble gases He, Ne, Ar, Kr, Xe, Rn
H2O = water

CO_2 = carbon dioxide
CH_4 = methane
NH_3 = ammonia

--enriched in the gas giants: Jupiter, Saturn, Uranus, Neptune

REFRACTORY **ELEMENTS:**

--those that tend to form solids, even at relatively high temperature:
Ca, Al, Ti: condense at 1500 to 1300oC
Fe, Ni, Co, Mg, Si: condense at 1300 to 1000oC
(H_2O = water: condenses below 100oC)

--enriched in the rocky, or terrestrial, planets: Mercury, Venus, Earth, Mars
(and the asteroid belt, which is a rocky planet that failed to form).

Origin of Earth:

As a result of collisions, planetesimals accrete. This process ultimately forms Earth and the other rocky planets.

ORIGIN OF THE EARTH BY ACCRETION

The Earth formed by accretion of planetesimals that were *cold* prior to infall:

1. The Earth is relatively depleted in noble gases,
which would be lost from low-mass planetesimals, whether they were hot or cold.

2. The Earth is relatively enriched in elements (H, C, N, O) that form volatile compounds such as water, CO_2, methane (CH_4), and ammonia (NH_3). At high temperatures these elements would have been lost, but at low temperatures they would have been retained as ***ices*** of these compounds.

The accretion was relatively *rapid*: it took (much?) less than 30 million years:

1. Accretion would have heated the protoearth, causing loss of volatile compounds from a small body. The Earth's mass must have been large enough to retain these compounds by the time it became hot.

2. At its present mass, Earth is large enough to retain all chemical elements except H and He, which are continuously being lost to outer space.

ORIGIN OF THE MOON BY IMPACT

Hypotheses for the Formation of the Moon:
capture, fission, simultaneous accretion, impact.

And the winner is . . . *impact!*

- Moon has no metallic core (it stuck to Earth).
- Moon is dry (heat caused loss of volatiles)   and enriched in refractories.

- Off-center impact explains angular momentum of E-M system) and increased spin velocity of Earth.
- Note:
  --Uranus has large tilt of similar origin.
  --Venus only rotates once a year
  ➔ one day equals one year on Venus.

HOW OLD IS THE EARTH?

METEORITES: Most formed 4.56 +/- 0.01 Ga (billion years before present).

THE MOON:
1. Highland crust (formed from a magma ocean): 4.44 Ga
2. Major bolide (comet or asteroid) impacts: 4.5-3.9 Ga
3. Melting of the interior and eruption of the Mare basalts: 4.3-2.0 Ga

THE EARTH:

1. Age of the Earth is indistinguishable from that of the Moon and meteorites:
   4.56 Ga.
2. Accretion was probably largely complete by 4.4 Ga
   (<100 m.y. after planetesimals first form).
3. The oldest **minerals**:
   detrital zircons from much younger sediments in W. Australia: 4.4 Ga
4. The oldest **rocks**: the Acasta Gneiss in NW Canada: 4.02 Ga
5. The oldest **life**: NW Australia: 3.5 Ga
6. The oldest **rocks from the seafloor**: only 170 Ma!
   Why?