

INTRODUCTION TO ASTROBIOLOGY (SELBY CULL)

9/1/2010

"THE STUDY OF LIFE IN THE UNIVERSE"

study of the origins of life on earth

extremophiles, range of conditions where life can exist on Mars — better chance at finding where life can exist elsewhere

* Mars is a great opportunity for past life

* Titan is the only moon with an atmosphere

* Europa might have a liquid ocean beneath an icy surface

468 exoplanets

ASTROBIOLOGY

- STUDY OF THE ORIGIN & EVOLUTION OF LIFE
 - REQUIREMENTS FOR LIFE AS WE KNOW IT
 - ORIGIN OF LIFE ON EARTH
 - LIFE IN EXTREME ENVIRONMENTS ON EARTH
 - POSSIBILITIES OF LIFE ELSEWHERE IN THE UNIVERSE

- INTERDISCIPLINARY

- BIOLOGY, GEOLOGY, ASTRONOMY, CHEMISTRY, PHYSICS, ATMOSPHERIC SCIENCE

0105

COURSE GOALS (YEAR 1) HABITABILITY OF EXTRATERRESTRIAL ENVIRONMENTS

- BY THE END OF THIS COURSE, STUDENTS SHOULD BE ABLE TO EVALUATE COMPETING HYPOTHESES FOR ASTROBIOLOGICAL

ISSUES SUCH AS: ~~involving various~~

~~two scenarios~~ ~~of life~~ ~~models for the origin of life on~~

~~Earth~~ ~~and~~ ~~habitability~~

- EVIDENCE FOR EARLY LIFE ON EARTH
- BOUNDARY CONDITIONS FOR HABITABILITY
- STRATEGIES FOR SEARCHING FOR LIFE IN THE SOLAR SYSTEM

Y=45°
P-conc=60%
Oxides
Z=+600°C
X=5000K
t=6000s

THE DRAKE EQUATION:

$$f = f$$

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c$$

\downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow

of rate % # % % %

civilizations stars/ Stars planets % like intelligent

in our stars w/ planets per star system

galaxy who have year w/ life w/ life

radio telescopes

\downarrow \downarrow \downarrow \downarrow

evolves advanced comm. advance technolo.

$$x L$$

\downarrow
lifetime of civilization

- VIOLATES ENTROPY

- PATTERNED MOLECULES
e.g. ATP, DNA/RNA

- RESPONDS TO STIMULI
- TEMPORAL

DEFINING "LIFE"

- REPRODUCES

- FOOD/WASTE

- ORGANIZED

- SELF-CONTAINED

- EVOLUTION

- HOMEOSTASIS

- GROWTH/REPAIR

- GENETIC MATERIAL

- WATER-BASED

- ADAPTATION

- AUTO-CATALYTIC

- CYCLICAL

L.A.W.I.I. (Life As We Know It)

- ① GENETIC MATERIAL → reproduction
 - ② CAPABLE OF EVOLUTION
 - ③ C.H.N.O.P.S. + water
 - ④ VIOLATES ENTROPY
 - ⑤ Cellular → homeostasis
-

Origin of the Universe
How Stars form and Die

9/8/2010

Stuff in the Universe

- ① - Planets + moons
- ② - Stars: burning Hydrogen
- ③ - Nebulae: interstellar gas → OORT CLOUD
- ④ - Comets: big chunks of ice
- ⑤ - Asteroids: rock → Kuiper belt
- ⑥ - Black Holes: supermassive bodies
- ⑦ - Pulsars: burned-out dead stars
- ⑧ - Supernovae: exploding stars
- ⑨ - Galaxies: lots of stars in a system
- ⑩ - Quasars: centers of ancient galaxies

HOW FAR AWAY? (from us)

A MAP OF THE UNIVERSE

1. The universe is 3D.
2. The universe giant - 90 billion lightyears across
3. As we look out across the Universe, we look back in time.
4. Our map will be the Universe as we see it - not as it is.

distance light
travels in a year

9/22/2010

G=billion

HISTORY OF SOLAR SYSTEM

4.57 Gya - Sun

4.567 Gya - Chondrules
→ planetesimals
→ protoplanet

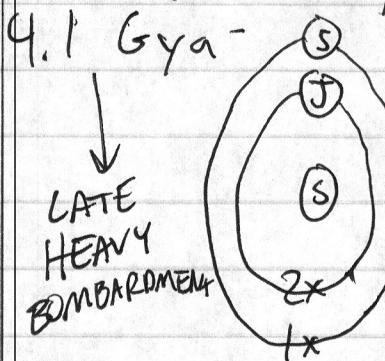
4.54 Gya - Accretionary disk gone

4.53 Gya - Iron Catastrophe (Differentiation)

4.52 Gya - Big Whack



4.45 Gya - Heavy Bombardment



- Jupiter/Saturn 2:1 resonance
- Neptune pushed further out
- causes late heavy bombardment

3.8 Gya - End of late heavy bombardment

Earth's Water? (none ~~is~~ on surface after differentiation) *where'd it come from?*

- ① Comets?
- ② less radiation from Sun = H₂O stable?
- ③ Asteroids?
- ④ Outgassing from Volcanoes?

How to test?

- compare pH levels
- isotope analysis → Deuterium: Hydrogen ratio suggests ↓ Asteroids & Outgassing

NO CLASS

9/29

10/13

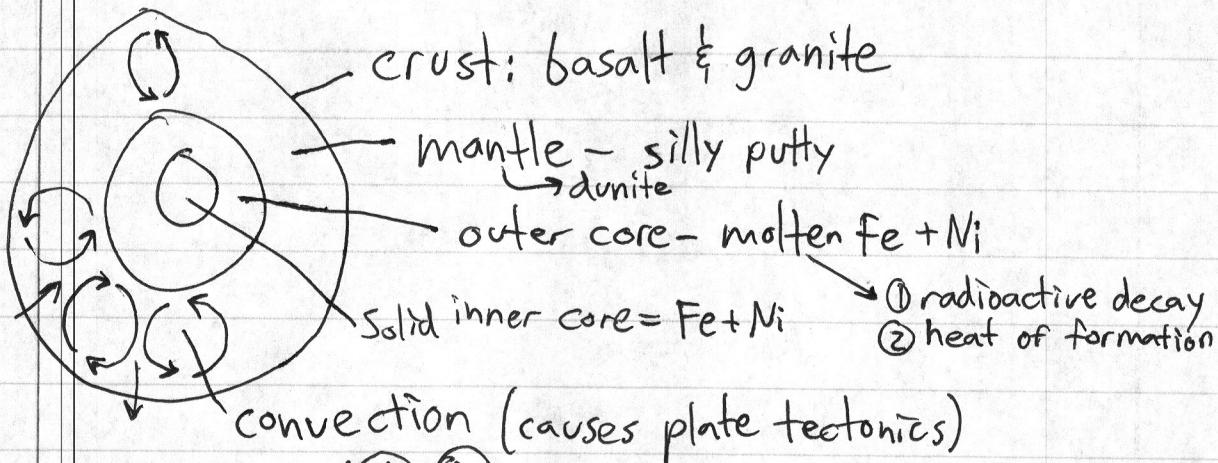
11/24

E.C. opportunity: game w/ rock cards

9/22/2010

40% of stars that we're looking at have planets

EARLY EVOLUTION OF THE EARTH



convection (causes plate tectonics)

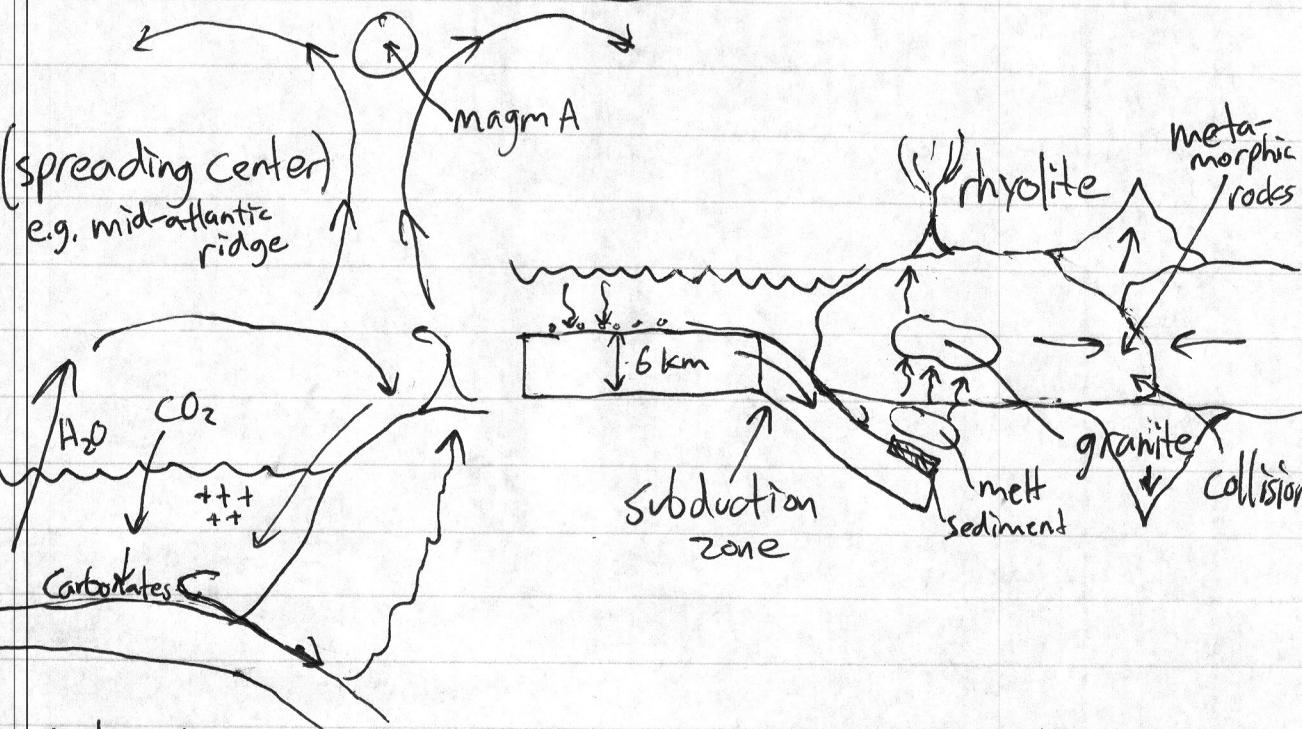
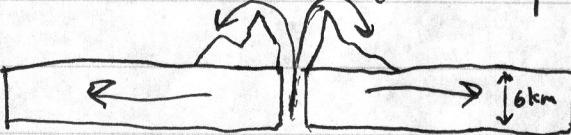


plate tectonics are intimately involved with water cycle, carbon cycle

→ located in the Local or Orion arm
(comes off Sagittarius arm)

Our solar system - 1 lightyear (oort cloud) Alpha Centauri

Milky Way Galaxy - 100,000 lightyears

↳ 2 main arms (Sagittarius & Perseus) → center at Sagittarius A*

↳ eating Large & Small Magellanic Clouds (tiny galaxies)

Andromeda - 2.5 million light-years away

Virgo Supercluster of Galaxies

↳ The Great attractor (pulling everything in vicinity)

Quasars - at the edge of observation, just before ~~the edge of the universe~~

Cosmic Microwave Background (C.M.B.) 2° kelvin

The Origin of the Universe (THE BIG BANG)

- Everything at Unity - pushed down to one small point

↳ Space, matter, and energy all condensed

$t = 0 \text{ sec} \rightarrow$ [Space]

pure energy

Grand Unification Epoch

strong - holds together neutrons

weak - holds proton & neutron

gravity - mass

electromagnetic - e^-

(quintessence) - dark energy?

$t = 10^{-43} \text{ sec}$

→ gravity split off from the other forces

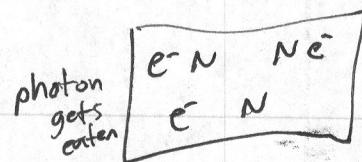
$t = 10^{-43} \text{ sec} - 10^{-36} \text{ sec}$

(other forces break off)

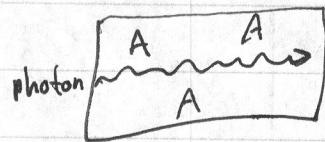
→ Inflationary Epoch $\rightarrow 10^{26} \times$ more voluminous $\xrightarrow{\text{less size}} \text{Temp.} \downarrow$

$t = 10^{-30} \text{ sec} \rightarrow$ Higg's Boson? (gives mass to particles through higgs field) 900 md. K

$t = 10^{-12}$ sec \rightarrow Quarks



$t = 10^{-6}$ sec \rightarrow Protons & Neutrons



$t = 1/\text{sec} - 10\text{sec} \rightarrow e^-$

$t = 3 \text{ min} \rightarrow$ Nucleo synthesis

\rightarrow protons + neutrons = nuclei (bunch of hydrogen)

↑ just nuclei!

$t = 380,000 \text{ years} \rightarrow$ Recombination (no photons survive)

\rightarrow nuclei + $e^- \rightarrow$ proper Hydrogen atoms

\rightarrow photons can now survive & travel to make MB.

$t = 500 \text{ million years} \rightarrow$ first stars, galaxies, & quasars

$t = 100 \text{ million years} \rightarrow$ 2nd generation of stars, more metal, Hydrogen

$t = 4 \text{ billion years} \rightarrow$ 3rd generation of stars, more metal

$t = 9 \text{ billion years} \rightarrow$ our sun starts to form

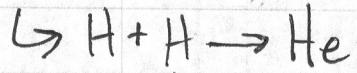
9/15/2010

Universe is totally hydrogen, first stars formed in dense areas

1st Stars - ~~almost~~ exclusively Hydrogen, fusion



gravity causes high pressure
radiation pressure fleeing



3 million °K

1 million years old

STAR FORMATION:

① NEBULA - gas (H)

high gravity

② Perturbation

\rightarrow interact (collide) w/ dense thing (black hole) (galaxy)

\rightarrow supernova \rightarrow big star

③ Fragmentation

\hookrightarrow BOK Globules

④ Gravitational Collapse \hookrightarrow + little bit of radiation pressure

⑤ Protostar \hookrightarrow heat pushing outward

⑥ T-Tauri Star - radiation = gravitational (particles get pushed away from radiation)

\rightarrow \rightarrow \rightarrow gravity & radiation take turns winning
star gets smaller

6A

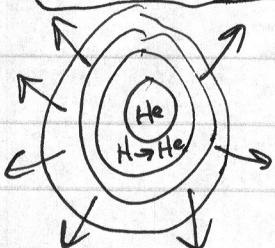


Herbig-Haro Objects (Jets of material get sent off in either direction)
 RADIATION causes fleeing material,

Core gets to 3 million°K → **FUSION!**

⑦ Main Sequence Star - 10 billion years

(our sun is 4.57 billion years old)



core burns up all its hydrogen, no radiation
gravity starts to win, makes bigger core
successively from heat radiating cooling

⑧ Red Giant - core gets close to edge, causes expansion & cooling
H → He outer shells "Helium Flash"
core: He → C, N, → Fe

⑨ Planetary Nebula

↳ puffed up outer shell of a star that's expanding into space

⑩ White Dwarf

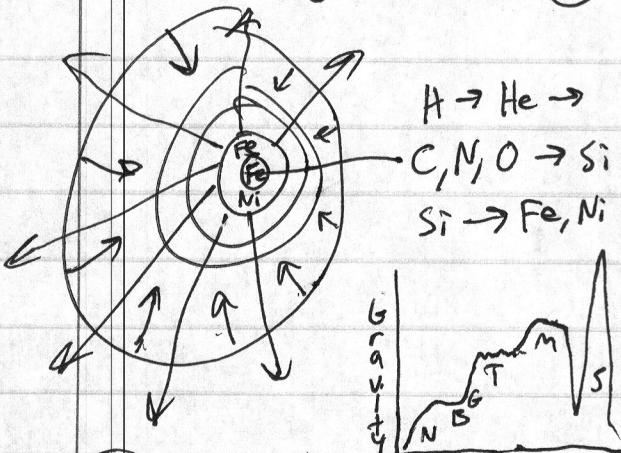
↳ left over burning core after outer layers leave

SUPERNOVA

mass of the sun

* if

> 8x M_{sun}



(10B)

SUPERNOVA:

happens in a fraction of a second:

core becomes Iron, Nickel, can't fuse any more
Fusion shuts down, permanently
gravity wins,
material gets pulled toward Iron core
nuclei in iron core gets ripped apart
mass rebounds into supernova

⑪ Burnt out core

→ Neutron Star

makes heavier elements

Planet Formation:



(lasts 10 million years)

⑫ Accretion Disk
⑬ Planetesimals

or
or
or
if

Pulsar

20x M_{sun} = Black Hole

or

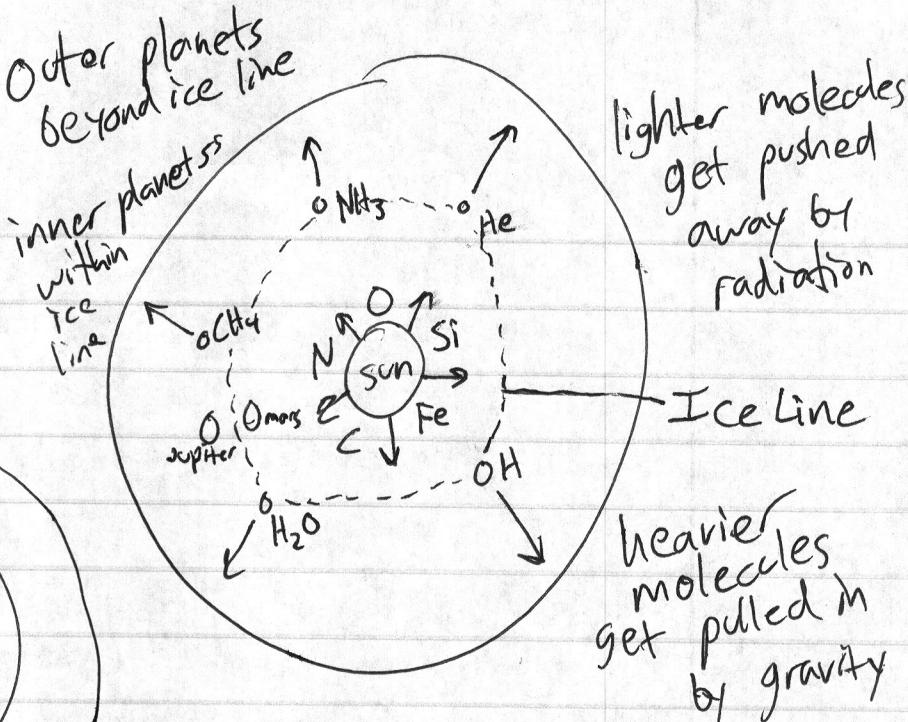
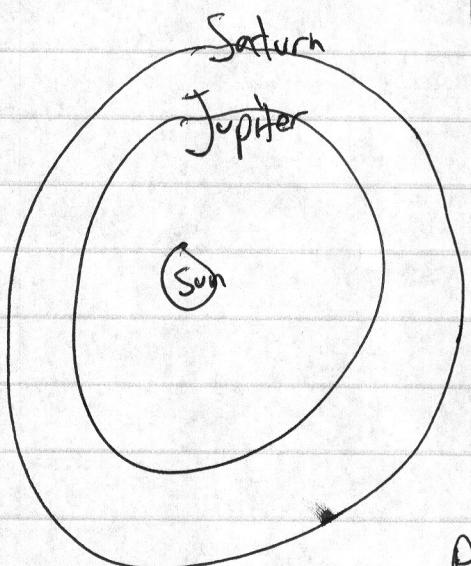
if

1.5

disk

chondrules: first little bits
(molten) of dirt that
came together to form planetesimals

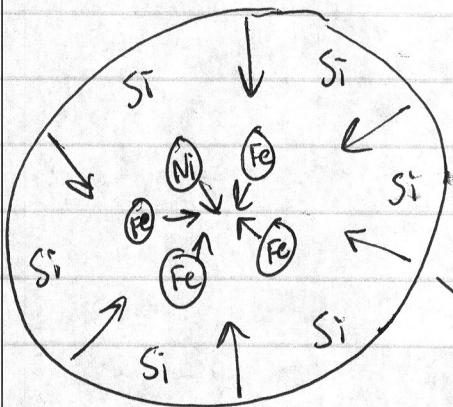
③ Protoplanet



resonance (Jupiter, Saturn orbits line up)
2 Jupiter orbits = 1 saturn

planetary migration (gravity waves from J+S pushes Neptune)

Composition of Protoplanets beyond Uranus



Differentiation: heavier elements get pulled to core
(Iron, nickel)
(from heat from accretion)
Creates magnetic field

PLANET FORMATION:

"NEBULAR HYPOTHESIS" what would we expect to see

- ✓ Rocky close to sun
- ✓ All in same plane
- ✓ Impact Basins
- ✓ Discrete, nearly circular orbits
- ✓ Asteroid belt & Kuiper belt & Oort Cloud

~~DEINOCOCCUS~~ DEINOCOCCUS RADIODURANS - bacterium that can survive at the center of nuclear reactors
 MIDTERM DUE OCT. 20

10/6/2010

4.57 Gya - Sun form

4.567 Gya - Chondrules
 - Planetesimals
 - Protoplanets

4.54 - accretionary disk gone (radiation from T-Tauri)

4.53 - Iron Catastrophe

4.52 - "Big Whack" - Moon formation -

4.51 - Basalt Crust

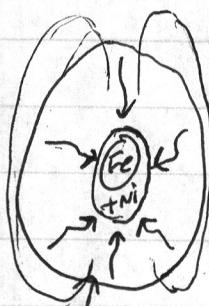
↳ most primitive Earth rock

4.45 - Heavy bombardment ends

4.1 - Jupiter/Saturn resonance

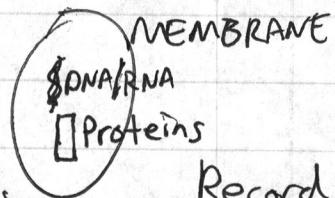
2:1 orbits = crazy = Neptune pushed out
 Late Heavy Bombardment

3.8 Gya - End of LHB



differentiation;
 forms magnetic field

EXTREMOPHILES:



	Challenges	Adaptations	Record	Name
Temp ↑	Denatures Protein DNA breaks down Membrane meltdown	special proteins that don't denature always repairing at high temps saturated fats + special proteins in bilayer	121°C Strain 121	Hyperthermophiles
Temp ↓	slow metabolism ice crystal formation frozen membrane	protein antifreeze special proteins in bilayer	-20°C [chemolithoautotrophs]	cryophiles/ psychrophiles
Pressure ↑	metabolism slow ↓ permeability of membrane (turns to wax)	special proteins in bilayer	1170 bars	barophiles/ piezophiles
Pressure ↓	cell burst? dehydration	3 spores		Ø (pure survival)
Pure Acid H^+ H^+ H^+	ATP production shuts down (no ion gradient) denatures protein	tons of ion proton channels (more pumps)	-0.06 pH	acidophiles

Name
10/20/2010

Challenges Adaptations

Record

high
alkalinity
(high pH)

↓ respiration
↓ ATP production proton pumps

13 pH

alkalophile

radiation

denaturing
DNA breakdown

repair mechanisms
duplicate genomes
manganese accumulation

15,000
greys
(humans
<5 greys)

Deinococcus
Radiodurans

Radio-
resistant
[*Tardigrades*]

0% oxygen

dehydration
salting out
(↓ in protein solubility)

↑ organics inside
+ anti-salt proteins
(amino acids)

37% salt
(3% = sea)

anaerobic

halophytic

high salt

dry up

embedded
w/ sugars

120 years
(tardigrades)

Xerophiles

No water

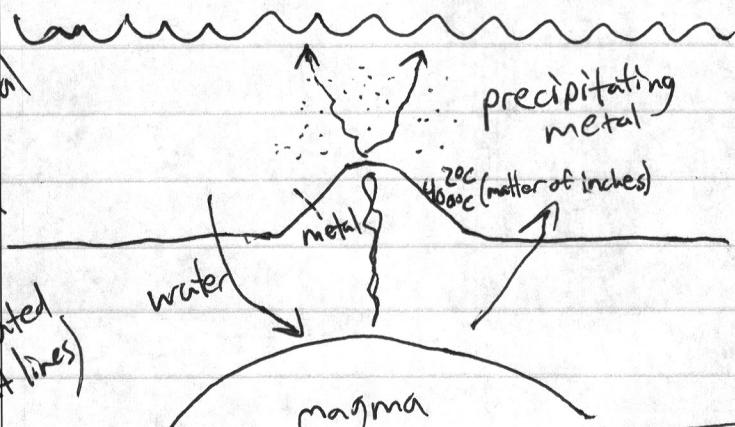
high metal

denature proteins suicide proteins

Gold, Nickel,
Cadmium, Mercury,
Copper

metalo-tolerant

halothermal
vent
(usually associated w/ fault lines)



pompeii worms
scaly-foot gastropod

Acid Mine Drainage

pyrite

sulfuric acid

endoliths
(live inside rock)
endospores (outer space)

Pro-microfossils

- morphology - hollow
- composition - carbonaceous?
 - biogenic kerogen

→ - cell walls
 - evidence of division
 - tears @ points of flexure
 - edges taper & don't break
 - look like cells
 (sinuous)
 in reasonable environments

- C - isotopic composition - $\delta^{13}\text{C} = -26\%$

- mode of preservation - petrification

ANTI-microfossils

- carbonaceous → graphite (hydrothermal) → isotopic?
- timeline = suspicious
- distribution & orientation suspicious
- morphology - on a gradient
- composition - formed around chalcedony (quartz)
 - hydrothermal

	<u>Mercury</u>	<u>Venus</u>	<u>Earth</u>	<u>Mars</u>	10/27/2010
Distance from sun	0.4 AU	0.7 AU	1 AU.	1.5 AU	
Size	40%	95%	100%	50%	(diameter)
Composition	70% metal 30% rock	35% metal 65% rock	"	25% metal 75% rock	
magnetic field	✓	X	😊	😢 (but past evidence yes)	
atmosphere	a few stray H+He	very thick CO ₂	N ₂	thin CO ₂	
water	X	X	😊	X	
surface	No	Maybe	Yes	No	

RNA → Nucleobases + Sugar + Phosphates

① Meteorite

② Cyanide + UV light
(HCN)

③ HCN + NH₃ + light

④ Cyanoacetyline + cyanate

① Formose

reaction:
formaldehyde
+ clay

form
naturally
(run-off)

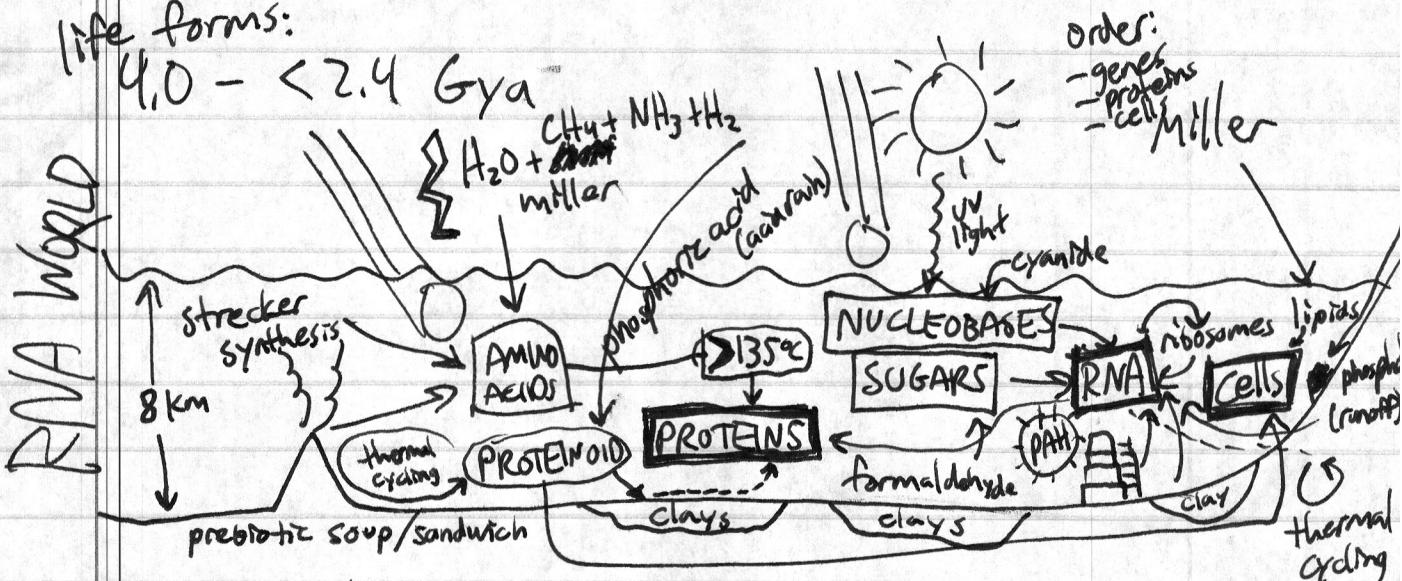
Protocells

① lipids → Miller experiment

② Proteinooids + water → OOO (little bubble things)

life forms:

4.0 - < 2.4 Gya



Problems w/ RNA World

- ① Concentrating in reasonable timespan
- ② In-elegant
- ③ RNA → codes for everything
- ④ Wrong gasses in atmosphere?

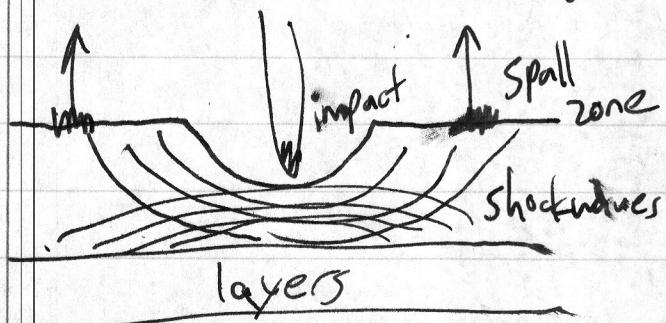
PANSPERMIA

IMPACT

pressure - > 120 million bars

temperature - $> 2,700^\circ\text{C}$

acceleration - 20 million g's (2 sec) \rightarrow experiment: 100,000 shot into wall, 1 survived



EXTREMOPHILES

1170 bars

121°C

experiment: 100,000 shot into wall, 1 survived

SPACE

Vacuum \rightarrow endospores ✓ or inside of a rock

Extreme cold \rightarrow cryophiles / big rock (insulation)

radiation \rightarrow Deinococcus Radiodurans / big rock ($> 5\text{cm}, < 5\text{m}$)

No organi β /water \rightarrow endospores 😊

Time ~~(millions of years)~~ thousands to millions of years

RE-IMPACT

— burning up in atmosphere — big rock

— impact: temperature, pressure - $> 2,700^\circ\text{C}; > 120$ million bars
deceleration $3,000 \text{ km/hr}$

— new environment!

Paper Topics Due Next Week

11/3/2010

Hydrothermal vents
CO₂ Atmosphere?
Oceans?
Plate tectonics?

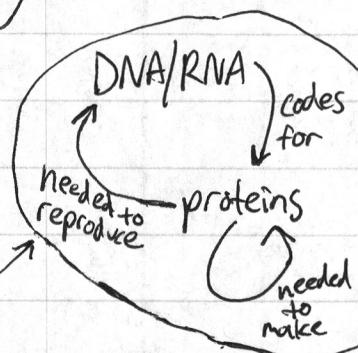
4.5 Gya - Earth Forms
4.1 - start of UHB
3.8 - end of UHB
3.5 - Apex Chert

↓
Life!

2.5 - fossils (sponges)
O₂ Catastrophe (caused by photosynthesis)

- reproduces
- self-contained
- ↳ homeostasis
- [temporal]
- metabolism

- ① membrane
- ② genetic stuff (RNA/DNA)
- ③ proteins



Vitalism

vital energy inside matter that made it alive/organic

chicken/egg problem of origin of life

Tests

- Lab: organic stuff → organic stuff
- Lab: non-living chemicals → organics?

★ abiogenesis

11/10/10

Proteins → amino acids

↓
proteinoids
phosphoric acid
+ amino acids

↳ ① Aldehyde + ammonia + cyanide

② Miller-Urey Experiment - H₂, CH₄, NH₃ + H₂O
③ Hydrothermal Vent
[(H₂, H₂S, CO, CO₂, CH₄)]
Glycolic acid

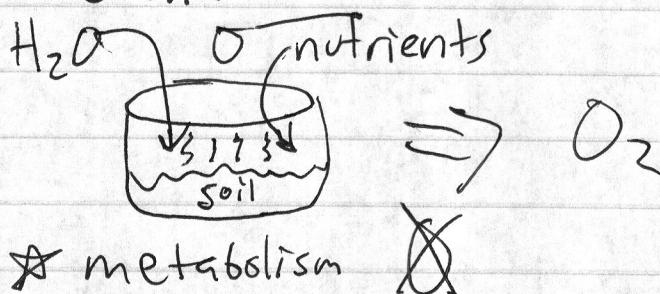
comp. of early earth atmosphere

④ Meteorites

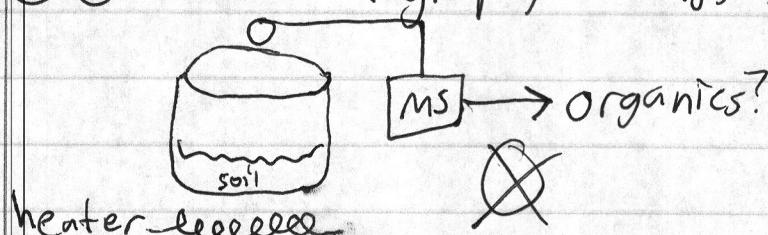
Wed, Dec - 8 - Class presentations (20 min each)
15 - no class
22 - final exam due (email) (no class) 11/17/2010
5-10 pages

VIKING EXPERIMENTS

① GAS EXCHANGE

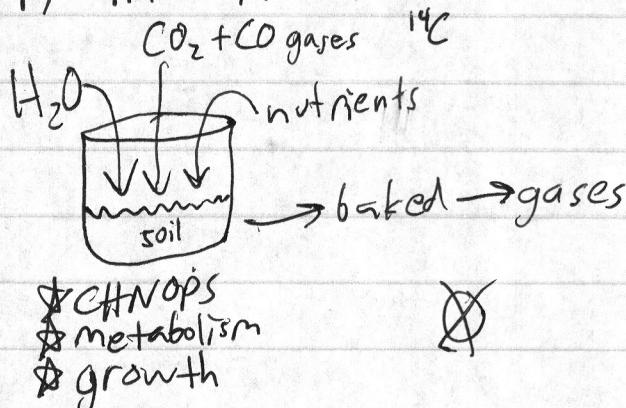


② Gas Chromatography - Mass Spectrometer

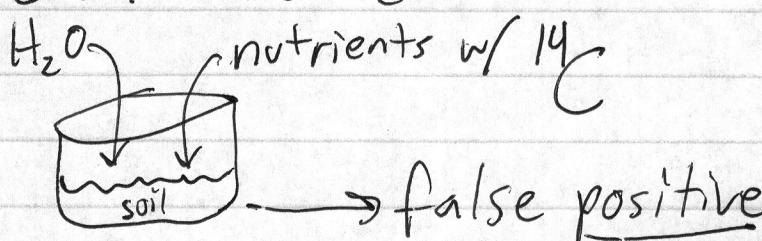


★ CHNOPS

③ Pyrolytic Release



④ Labeled Release



probably due to oxidizing agent (ClO_4^- , perchlorate)
★ metabolism

ASTROBIOLOGICAL POTENTIAL OF MARS

Radius \sim 1/2 that of Earth's

Mass \sim 1/10 of Earth's

Gravity \sim 40% of Earth's

Surface Pressure \sim 0.01 bars

\sim 1% of Earth's

Surface temp - 87° to $-8^\circ C$

usually $\sim -46^\circ C$

Atmosphere 96% CO_2

Liquid water is not stable on the surface

"Hemispheric Dichotomy" - ^(uncrateread) smooth, young north
cratered, ancient south

Geologic Time Scales: Noachian | Hesperian | Amazonian
4.6-3.5 Ga | 3.5-1.8 Ga | 1.8 Ga - Now

Martian Iron Catastrophe?

Modeling: Core \sim 1,450 km radius

\sim 43% of Mars' radius

Earth's Core \sim 3,500 km

\sim 55% of Earth's radius

Maybe partially fluid

POTENTIAL HABITATS FOR LIFE ON MARS

- ★ HOT SPRINGS / HYDROTHERMAL SYSTEMS
- ★ SUBSURFACE AQUIFERS
- ★ THIN FILMS OF WATER, NEAR ICE

"Evidence" of Life on Mars?

- ALH84001 (Mars meteorite)

- discovered in 1984 at Allan Hills, Antarctica
- formed ~4.5 Gya
- knocked off Mars ~15 Mya
- landed on Earth ~13,000 ya

★ 1996: David McKay

★ Evidence

- structures morphologically similar to fossilized bacteria (shapes, sizes)
- magnetic mineral structures similar to those constructed by some bacteria on Earth
- abundance of organic molecules (^{shape, size, composition} PAHs)

★ Counter-evidence

- Chemically, they're just carbon blobs
- Where are the cell walls?
- Evidence of Reproduction?
- Evidence of Growth?
- "Bacteria"- shaped, maybe, but not convincingly so.

Deuterium/Hydrogen ratio shows that Earth & Mars had different water sources

- Mars water more related to interstellar (comets, meteorites) water than Earth's

THERE IS WATER ON MARS

Evidence of Water ICE

1. Polar Caps

2. "Ice Lakes"

3. Snow/Frost

a - Viking 2

b - Phoenix

4. Subsurface Ice

a - craters

b - glacial features

c - MRO glaciers? (radar)

d - GRS observations (gamma ray spectrometer)

e - Polygonal terrain

f - Phoenix

g - Icy Craters

Evidence of Past Liquid water on Mars

1. Surface Water

2. Subsurface Water

3. Chemical →

a) channels

f) dendritic drainage

Evidence

b) inverted channels

networks

c) streamlined features

g) sedimentary layers

d) deltas

h) an Ocean? - thick, stable atmosphere
- faint young sun
- no carbonate materials
- Paradoxo

e) braided alluvial systems

2. Subsurface Water

- a.) Gullies
- b.) dark slope streaks
- c.) Sapping
- d.) Dissolved Minerals
- e.) Concretions

3. Chemical Evidence

a) Hydrated Minerals

- Phyllosilicate Group \rightarrow old Noachian terrain
 - "Clays" (4.5-4.0 Ga)
 - Stacked sheets of molecules
 - Trap water between layers
 - Low temperature aqueous environments
 - Not hydrothermal - happy pH \approx neutral
- Sulfate Group \rightarrow younger Noachian terrain
 - Have an SO_4^{2-} group (4.0 \sim 3.5 Ga)
 - Common in evaporite deposits - acidic pH
 - Common in hydrothermal systems
- Neither Phyllosilicate Nor Sulfate form after
- Major Martian Climate Change 3.5 Ga
 - Phylloian Epoch (4.5 - ~4.0 Ga)
 - neutral-alkaline environment
 - surface water + CO_2 = carbonate materials
 - Theikian Epoch (~4.0 - 3.5 Ga)
 - acidic environment
 - change maybe driven by: volcanic gases
 - volcanic gases
 - sudden drop in atmospheric pressure
 - coincides with dynamo shut-off
 - acid water + carbonate materials = CO_2

Martian Magnetic Field?

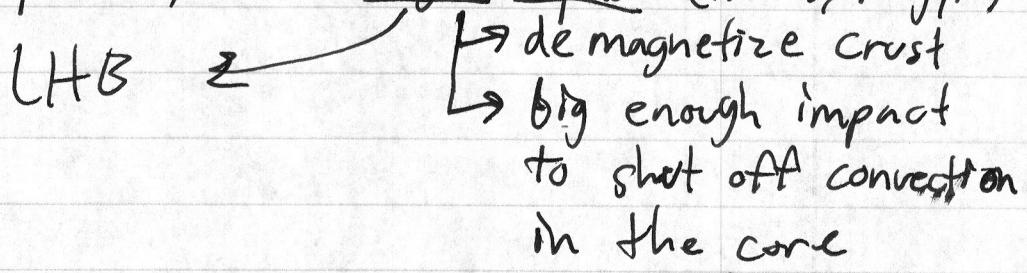
- No Global field today
- Evidence of a PAST field
- Mars Global Surveyor carried Magnetometer
- discovered magnetized rocks in crust

Mars' ancient magnetic field $\sim 30x$ stronger than Earth's

- crazy-strong magnetic field
- how did it go away? (approx 3.9gya) 3.8gya 3.9gya

↳ possibly from major impacts (Hellas, Argyre)

LHB



- shot off dynamo

Phobos & Deimos

- captured asteroids?
- current data & research supports they may have been formed out of Martian material (like our moon) but still unknown

Martian Meteorites

- The oldest mars rocks
- Martian Meteorite ALH84001

↳ dated at 4.5 Gya

- "SNCs" Shergottites, Nakhrites, Chassignites

~ 34 meteorites

- first identified in 1983 *Gas inclusions match Martian atm.