Kesler's Four Factors

- Geology
- Engineering
- Economics
- Environment

In the following five slides, we examine a piece from the Oregonian in terms of the above.

Malheur County targeted for gold, uranium mines

Richard Cockle, *The Oregonian*

Published: Sunday, January 08, 2012, 9:50 PM Updated: Sunday, January 08, 2012, 10:09 PM

ONTARIO -- Sprawling Malheur County could soon be in the spotlight as a mining hub -- or a battleground of uranium and gold mining interests vs. environmentalists trying to protect its lonesome sagebrush landscape. Australian-owned Oregon Energy LLC hopes to mine 18 million pounds of yellowcake uranium from the southeastern Oregon high desert 10 miles west of McDermitt near the Oregon-Nevada boundary. The go-ahead to mine the so-called Aurora uranium deposit could bring up to 250 construction jobs to the county, followed by 150 mining jobs. Meanwhile, Calico Resources USA Corp., a subsidiary of a Vancouver, B.C., company, may seek permits this month to chemically extract microscopic gold from a high desert butte south of Vale called Grassy Mountain, a project likely to create another 100 jobs.

Is there any description of geology in these paragraphs?

There is a bit of economics: employment in these projects.

Anything about engineering?

Any thing specific about the environmental impact of these projects?

Geology? Engineering? Economics? Environment?

The proposals will be the first real test of the 1991 chemical processing mining law passed by the Legislature in response to a debate over mining's future in Oregon, said environmentalist Larry Tuttle. The law ushered in tough new *bonding requirements* to weed out marginal operators and guarantee environmental cleanup.

Any geology here?
Legislation impacting a project comes under “economics”. Any specific economics?

Geology? Engineering? Economics? Environment?

Oregon Energy's proposal calls for extracting ore from a mile-long, 600-foot wide, 250-foot deep open pit 10 miles west of McDermitt and 3 miles north of the Oregon-Nevada border.

Plans call for the ore to be crushed and mixed with an acid solution in enclosed vats to leach out the uranium, he said. The acid would bond with the uranium and when dry become a sand-like powder called uranium oxide concentrate, or yellowcake.

Geology?
Engineering? Yes!
Economics?
Environment?

Geology? Engineering? Economics? Environment?

Tuttle, spokesman for the Portland-based Center for Environmental Equity, foresees environmental problems. The likelihood of sulfuric acid being used in processing the ore means it could remain in the mine tailings after milling, he said. The snag is that sulfuric acid tends to continuously leach out heavy metals that occur naturally in waste rock and tailings, contaminating ground water. "Just because you are through with the processing, years later you still have the issue with that interaction," he said. But probably the biggest environmental hurdle for the Aurora mine would be the release of mercury, Tuttle said. "The whole Owyhee Reservoir has been affected by naturally occurring background mercury," and uranium mining could release more, he said.

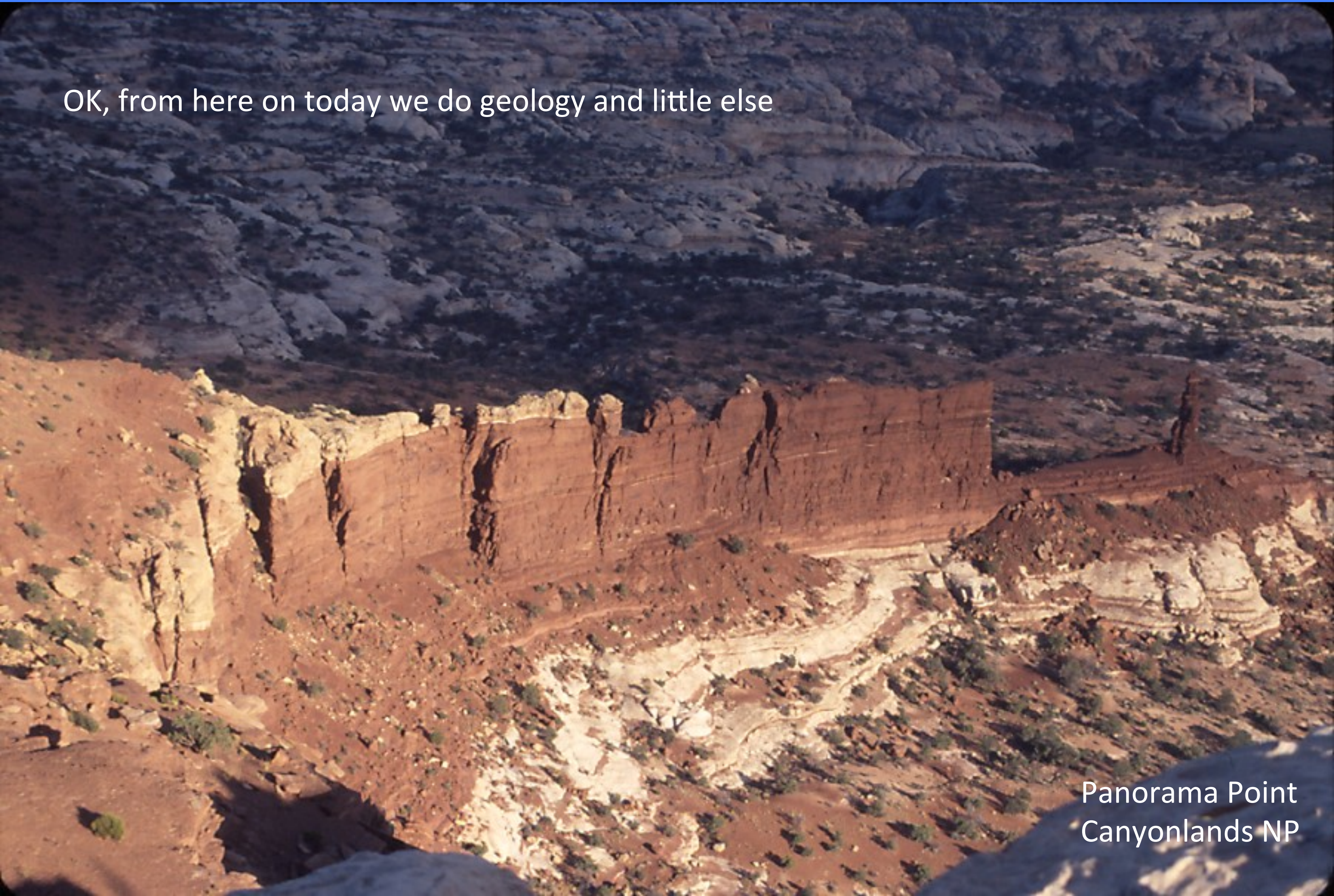
Geology? No
Engineering? A little, but the same as the previous slide
Economics?
Environment? Yes!

Geology? Engineering? Economics? Environment?

Public hearings will be held after the companies apply for permits to begin mining, said state geologist Vicki McConnell of Portland. Sixty-one acres of Grassy Mountain is patented, private mining land, but substantial portions of both sites are on federal land administered by the U.S. Bureau of Land Management. Both sites are remnant volcanic regions where geothermal and hydrothermal activity has pulled heavy metals and other substances close to the surface, McConnell said.

Geology? A little.
Economics? Yes, minerals rights (“patented”, BLM) are part of economics.
Engineering?
Environment?

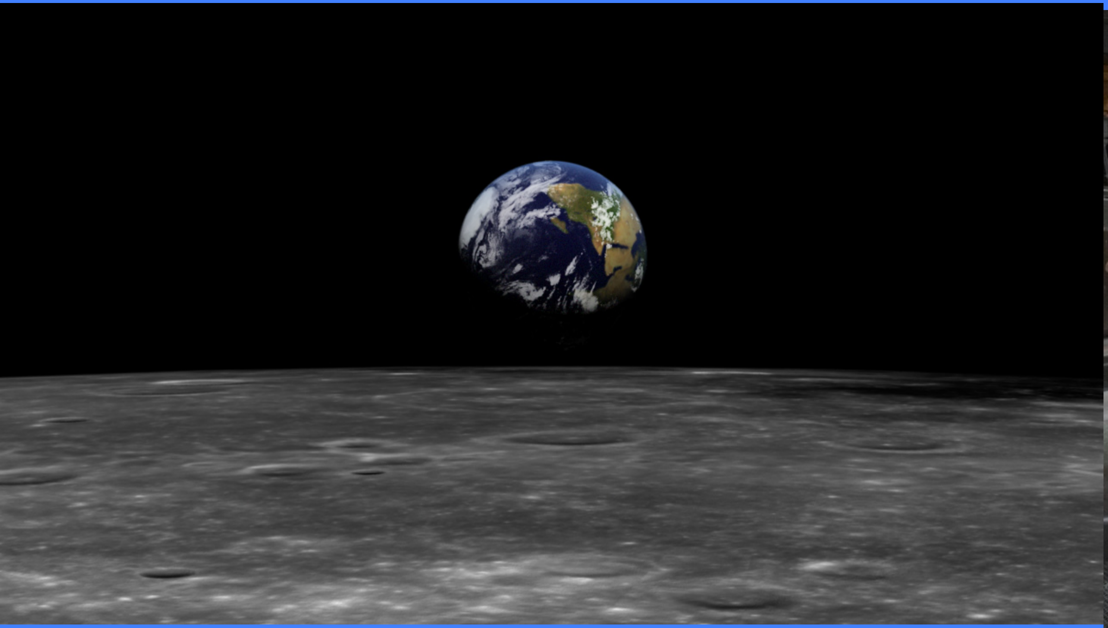
Geology



OK, from here on today we do geology and little else
Panorama Point
Canyonlands NP

What do these have in common?

The Moon and Earth



http://eoimages.gsfc.nasa.gov/images/imagerecords/3000/3020/apollo_lrg.jpg

The Willamette Meteorite

http://blog.oregonlive.com/clackamascounty/2007/10/BigMeteor.JPG

Galaxy Messier 81, Hubble and Spitzer telescope composite image

Meteorites, Earth, Moon, the Sun are thought to have formed in a spiral driven by gravity.

http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA09579

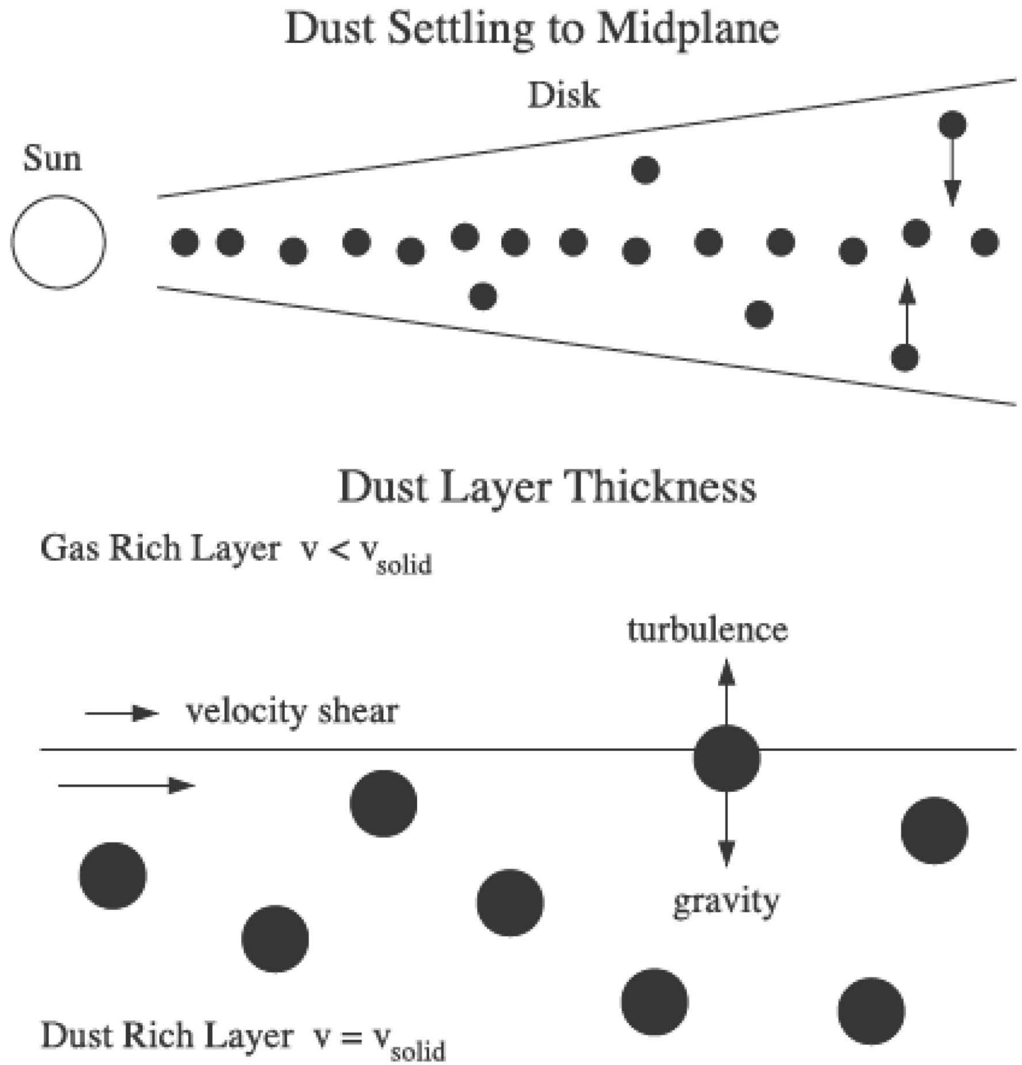


Fig. 1. Dust grains slowly settle to the midplane of the nebula due to the vertical component of the Sun's gravity, forming a solid-rich layer. This layer orbits the Sun slightly faster than the gas-rich layers above and below. The resulting wind shear generates turbulence, even if other sources of turbulence are absent. Thus, the solid-rich layer has a finite thickness.

The next three slides Illustrate a model that accounts for the formation of the solar system's planet and asteroids through gravitational processes.

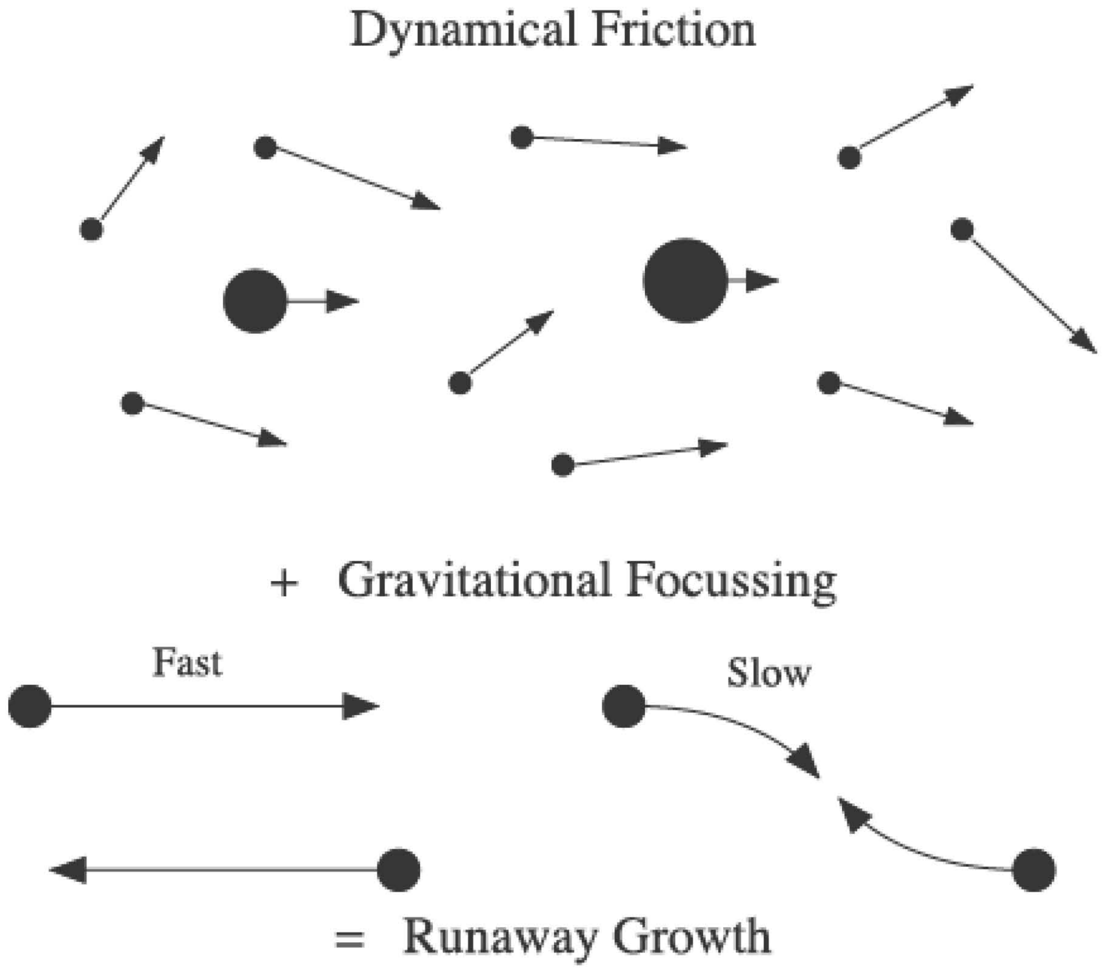


Fig. 2. The mechanics of runaway growth. Large bodies tend to have lower relative velocities than small objects as a result of numerous gravitational encounters. When large bodies pass close to each other, their trajectories are focussed by their gravitational attraction. Small bodies fly past each other too quickly to be significantly affected by their mutual attraction. Thus, large bodies grow faster than small ones.

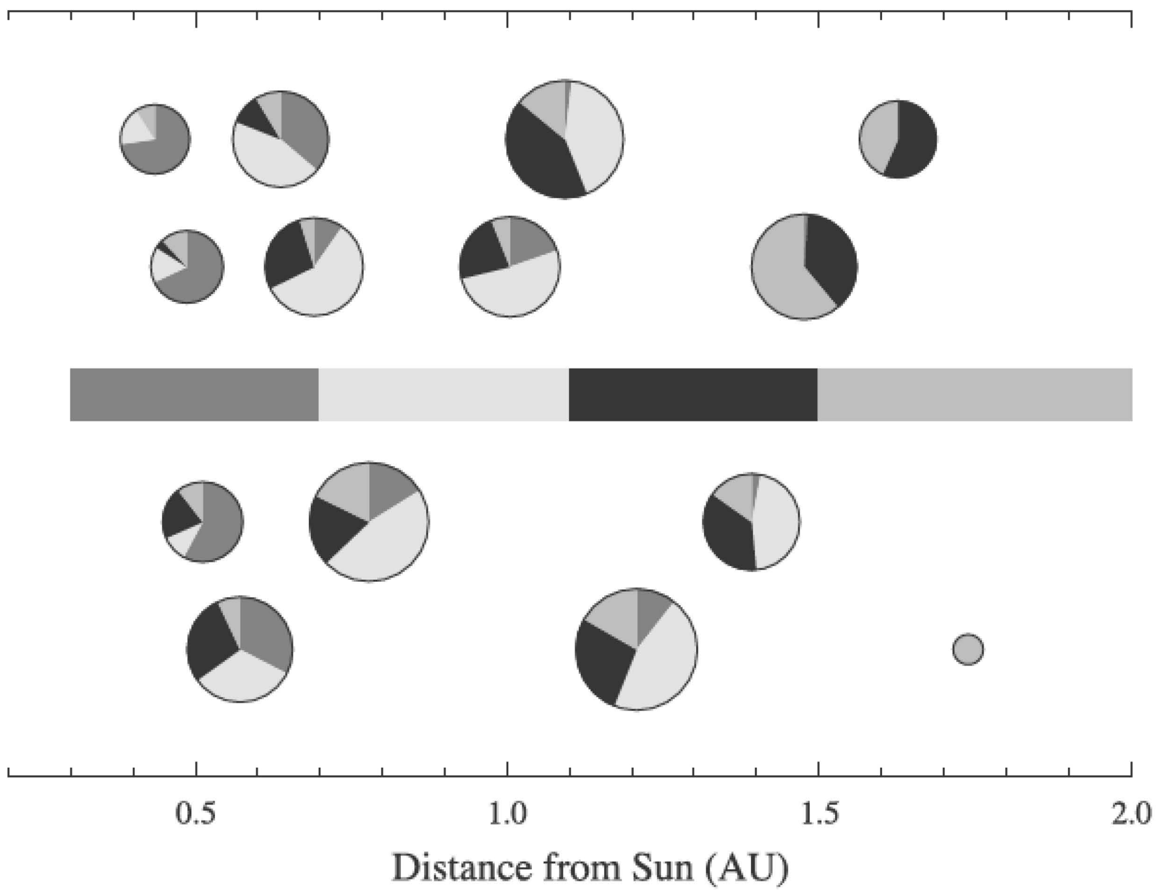
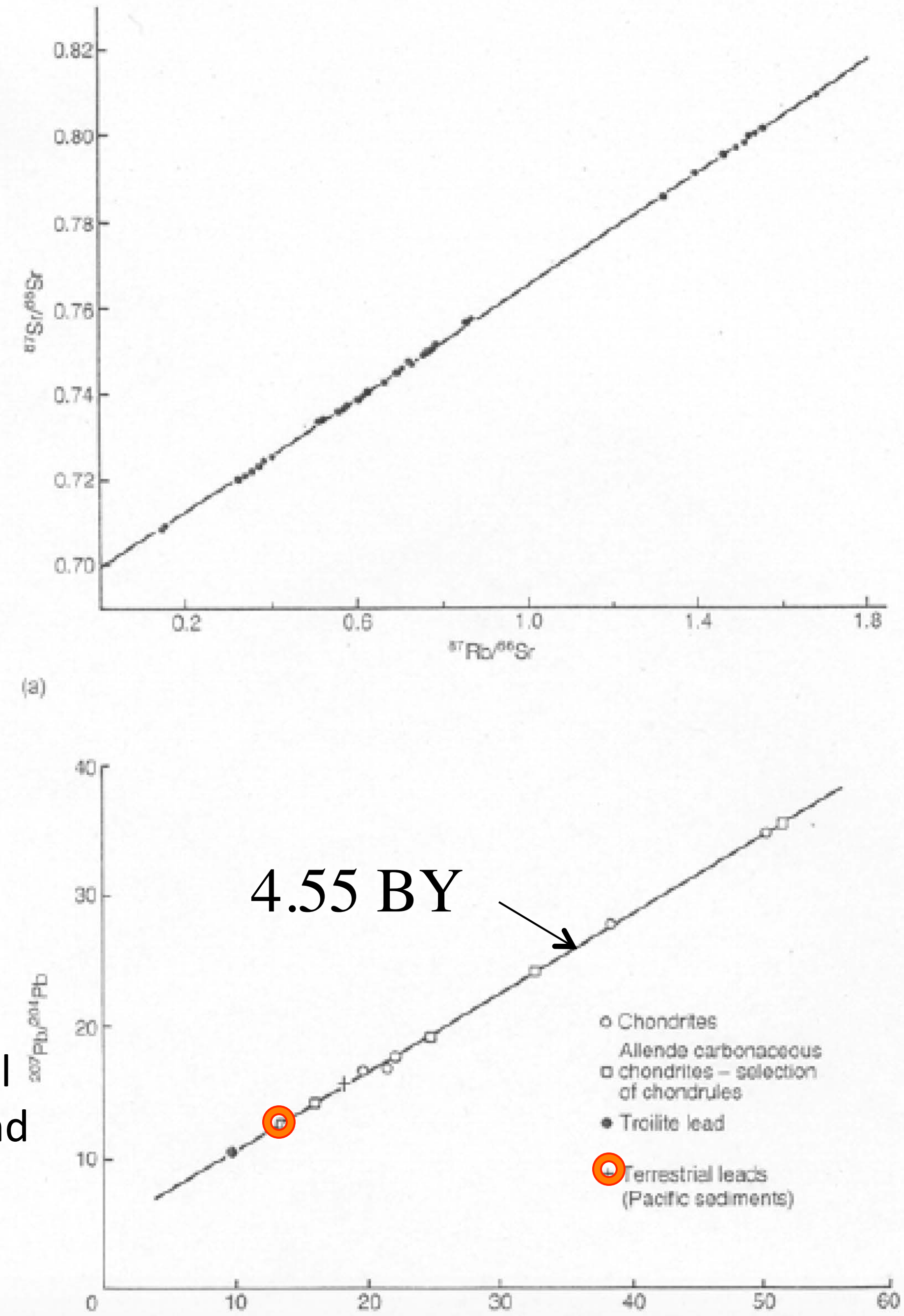


Fig. 3. The results of four numerical simulations of the final stage in the accretion of the inner planets. Each row of symbols shows one simulation, with symbol radius proportional to the radius of the planet. The segments in each pie chart show the fraction of material originating from each of the four zones of the nebula indicated by the shaded rectangles. In each simulation, the largest planet has a mass similar to Earth (results taken from Ref. [62]).

- Rb-Sr and Pb-Pb isochron diagrams for Meteorites



The age of the Earth:
Terrestrial sediments
Fall on isochron with
meteorites

This slide shows some chemical data that suggests the Earth and meteorites have the same age.

Figure 4.14 (a) Rb–Sr isochron plot of samples H and LL chondrites. T line has a slope correspo with an age of 4·555 ± (Ma (reproduced from M *et al.*, 1982). (b) Pb–Pb isochron plot of iron and stony meteorites. Its slo corresponds with an age 4550 ± 70 Ma. Note tha leads from terrestrial sediments fall on the sar isochron. (Based on Mu and Patterson, 1962.)

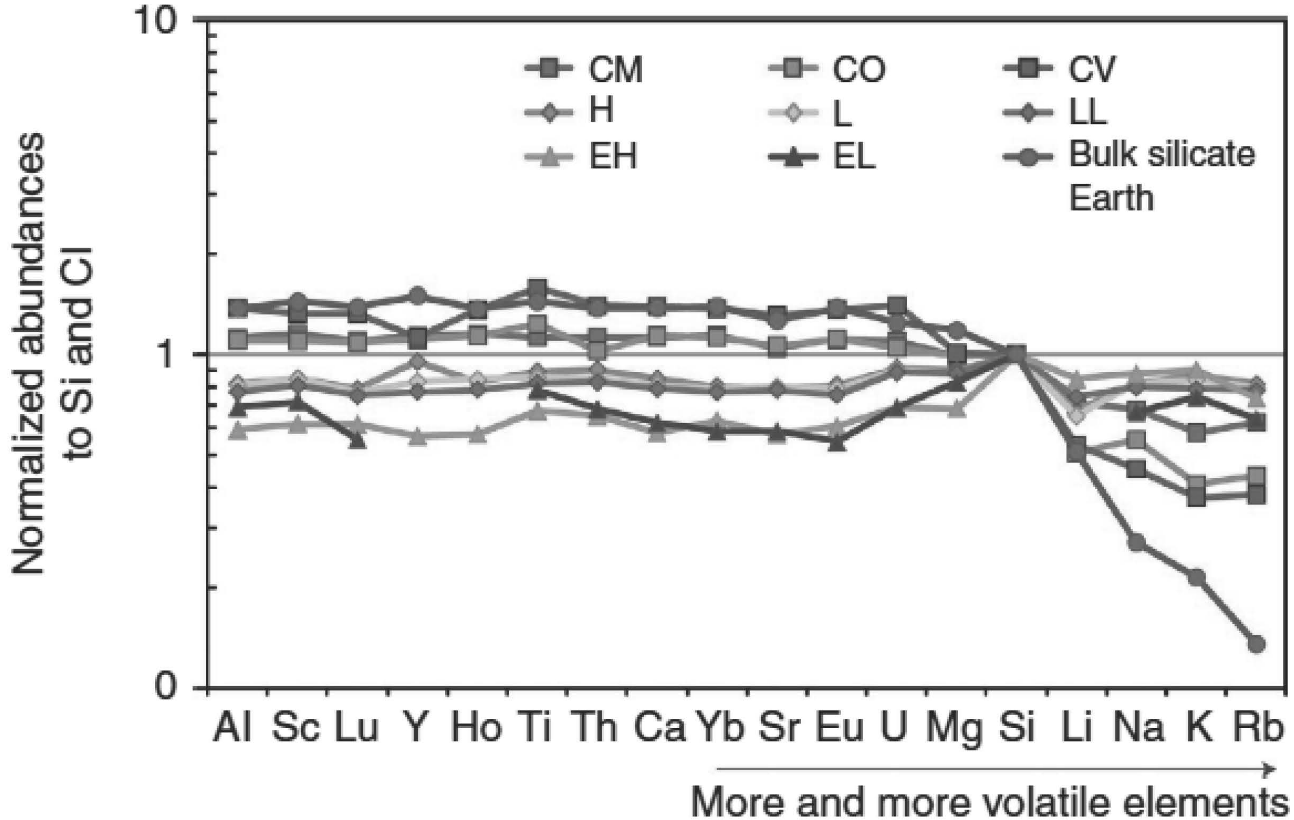


Figure 1 | Major chemical differences between the chondrites and the bulk silicate Earth (BSE). The abundances are normalized to Si and CI chondrites[11,12]. From left to right, the lithophile elements are reported with decreasing their 50% condensation temperature. The depletion of volatile elements in the BSE results from the erosion of crusts enriched with incompatible elements and the subsequent loss of the most volatile elements.

Boujibar et al 2016

This slide shows chemical data suggesting the Earth and eight meteorites have similar composition. However the Earth has lower concentrtions of volatile elements, those which turn to gas a lower temperature. Why?

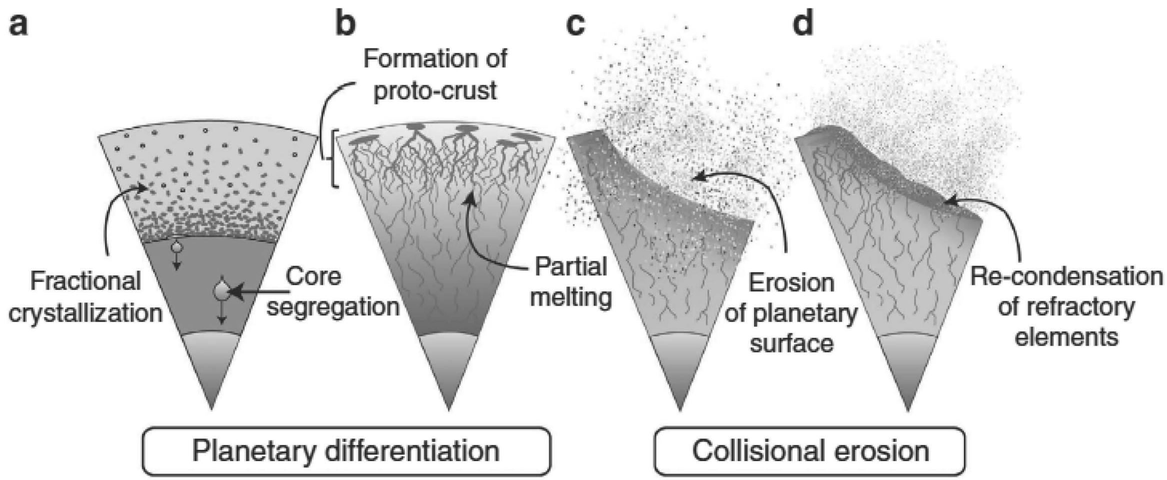


Figure 4 | Schematic model of chemical fractionation by collisional erosion. (**a**,**b**) Early heating leads to the rapid segregation of Fe-rich metal into the core. It is accompanied with the formation of a deep magma ocean[1] (**a**) and/or small-scale partial melting and formation of complex networks of veins and dikes[4] (**b**) which allows fast transfer of melts to the surface[4]. Both can yield compositional stratification of the mantle and the formation of an SiO_2-rich proto-crust. (**c**) The repeated collisions induce erosion of the proto-crust enriched in incompatible elements, as well as part of the planetary mantle. (**d**) Within the fraction of material volatilized by meteoritic impacts, re-condensation of refractory elements is favoured compared with the volatile elements.

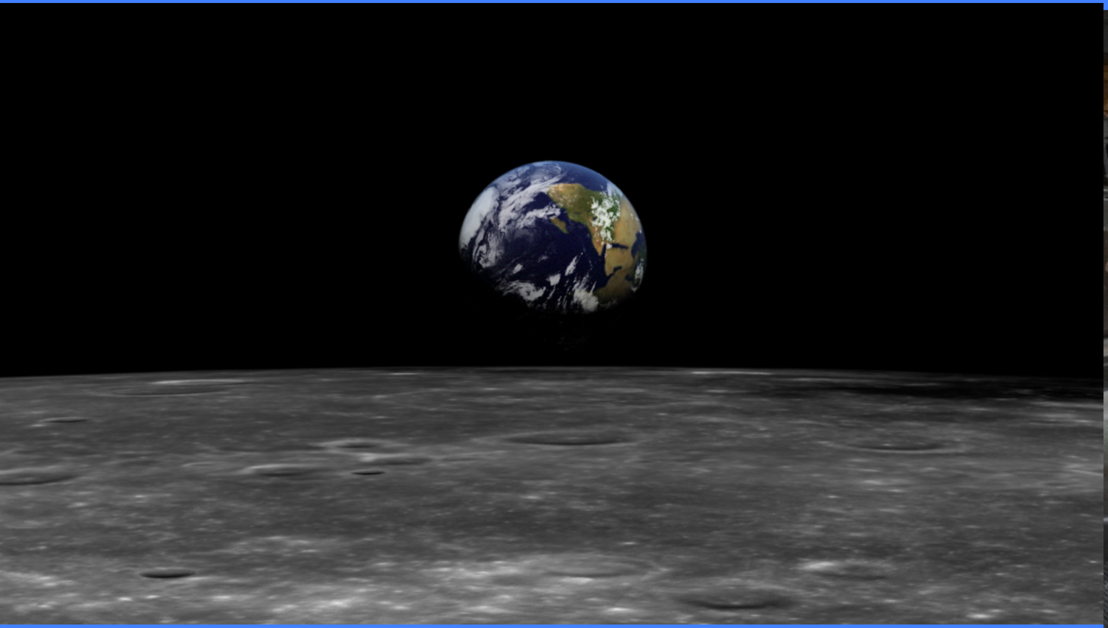
Boujibar et al 2016

This slide shows a model suggesting why the Earth has loss the more volatile elements, compared to the meteorites

What do these have in common?

The Moon and Earth

The Willamette Meteorite

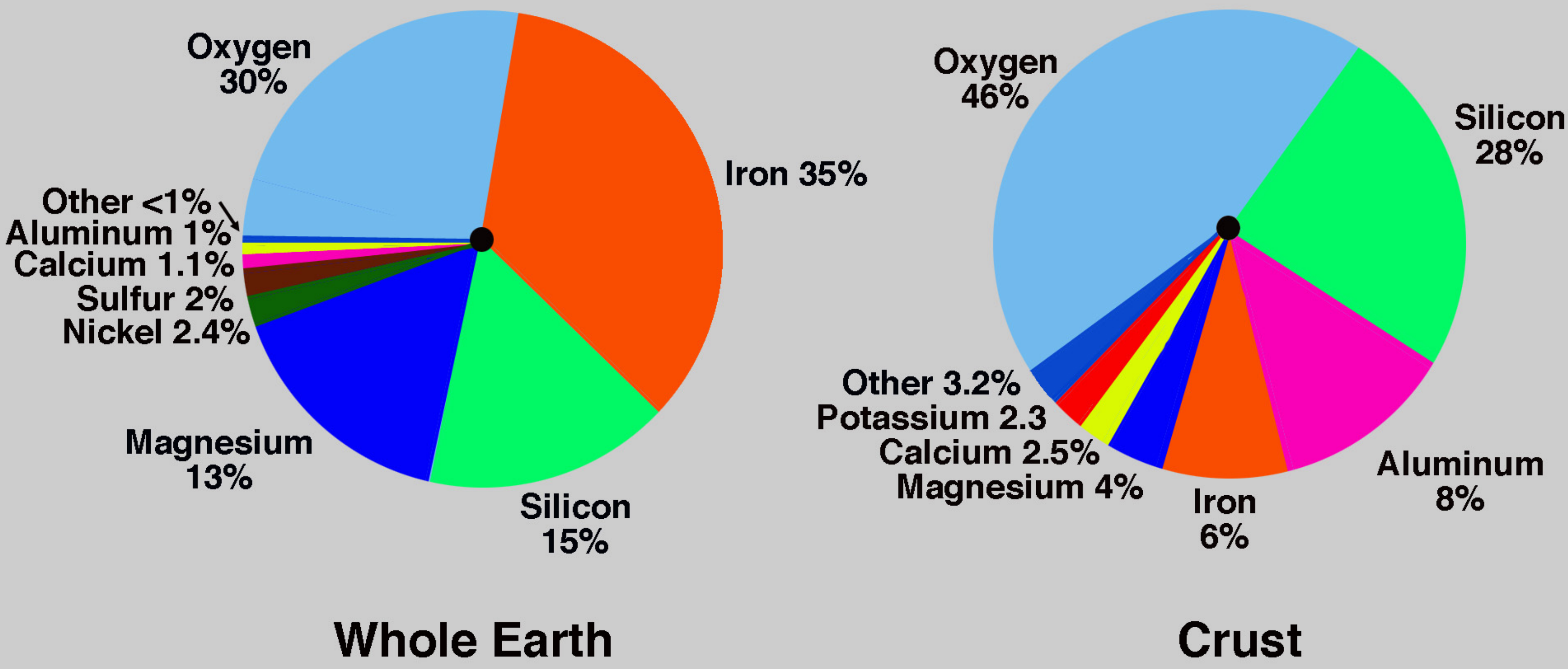


http://eoimages.gsfc.nasa.gov/images/imagerecords/3000/3020/apollo_lrg.jpg

http://blog.oregonlive.com/clackamascounty/2007/10/BigMeteor.JPG

So now you have some answers to this question.

What processes concentrate some elements in the crust?



However the "whole Earth" has a different composition from the crust. Why?

http://www.indiana.edu/~geol116/week2/earthcomp.jp

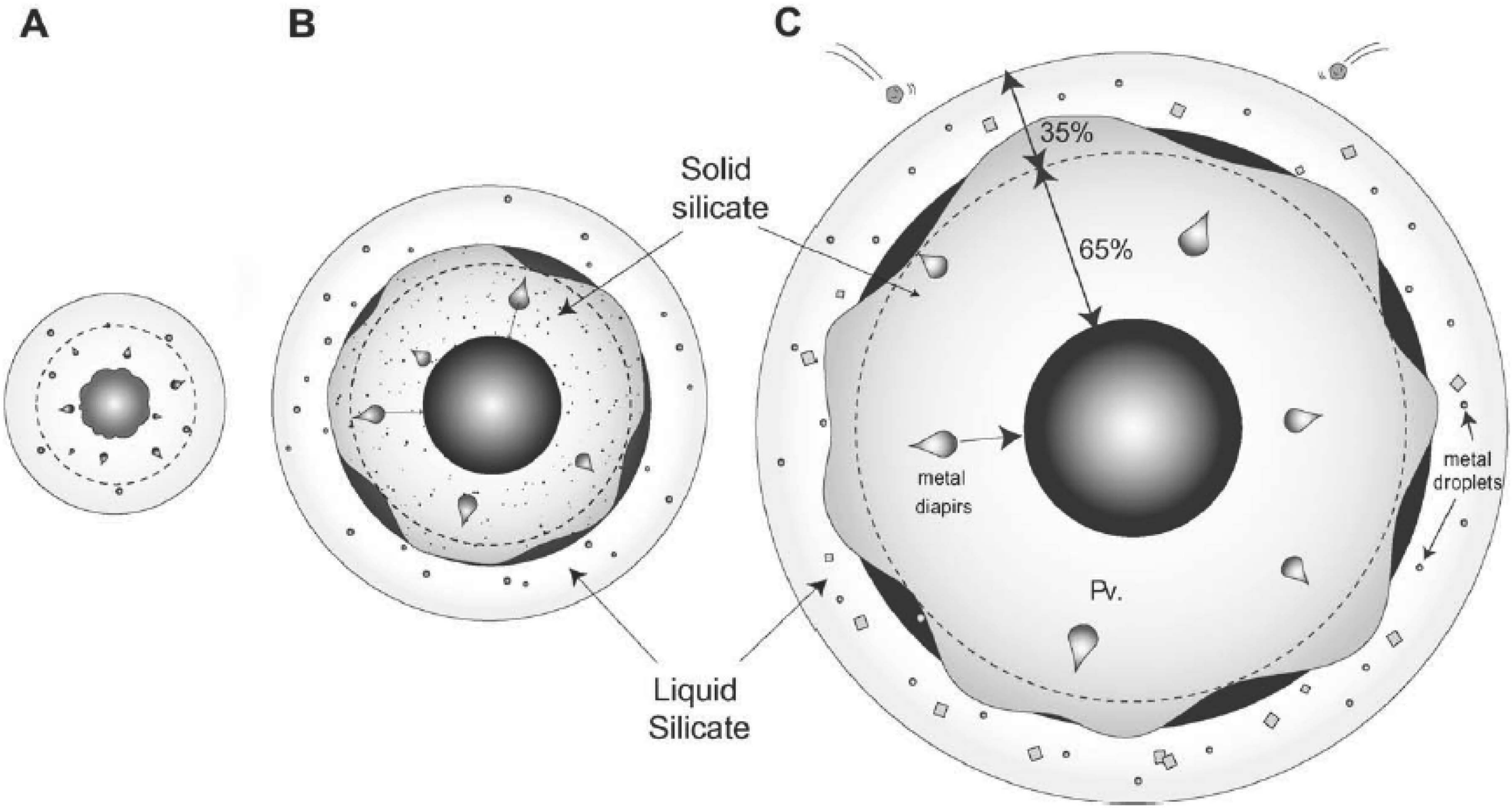


Fig. 5. Terrestrial growth model adopted in this study. As each increment is added to the earth, accreting metal is assumed to equilibrate completely with the mantle at a pressure corresponding to the base of the magma ocean. The metal is then isolated from the mantle and extracted to the core. For simplicity we assume a fixed depth ratio of upper (liquid) to lower solid mantle which, from partitioning of pressure-sensitive Ni corresponds to 35% of mantle depth.

Wood 2009

Most of the iron has sunk to the core, do to its greater density relative to other elements.

What did we just do? What have we learned?

We looked at some data.

We looked at some models.

With more time, we would ask if the data support the models.

The models suggest the Earth formed in a dust cloud.

Formation occurred at about the same time for Earth & meteorites.

Core-mantle formation modified original whole Earth composition.

Crust composition is different from whole Earth

Back to Earth: some useful vocabulary

Element	Wt % Oxide	Atom %
O		60.8
Si	59.3	21.2
Al	15.3	6.4
Fe	7.5	2.2
Ca	6.9	2.6
Mg	4.5	2.4
Na	2.8	1.9

This and the following slide define some terms we will use during the term.

Abundance of the elements in the Earth's crust

Major elements: usually greater than 1%

SiO_2 Al_2O_3 FeO* MgO CaO Na_2O K_2O H_2O

Minor elements: usually 0.1 - 1%

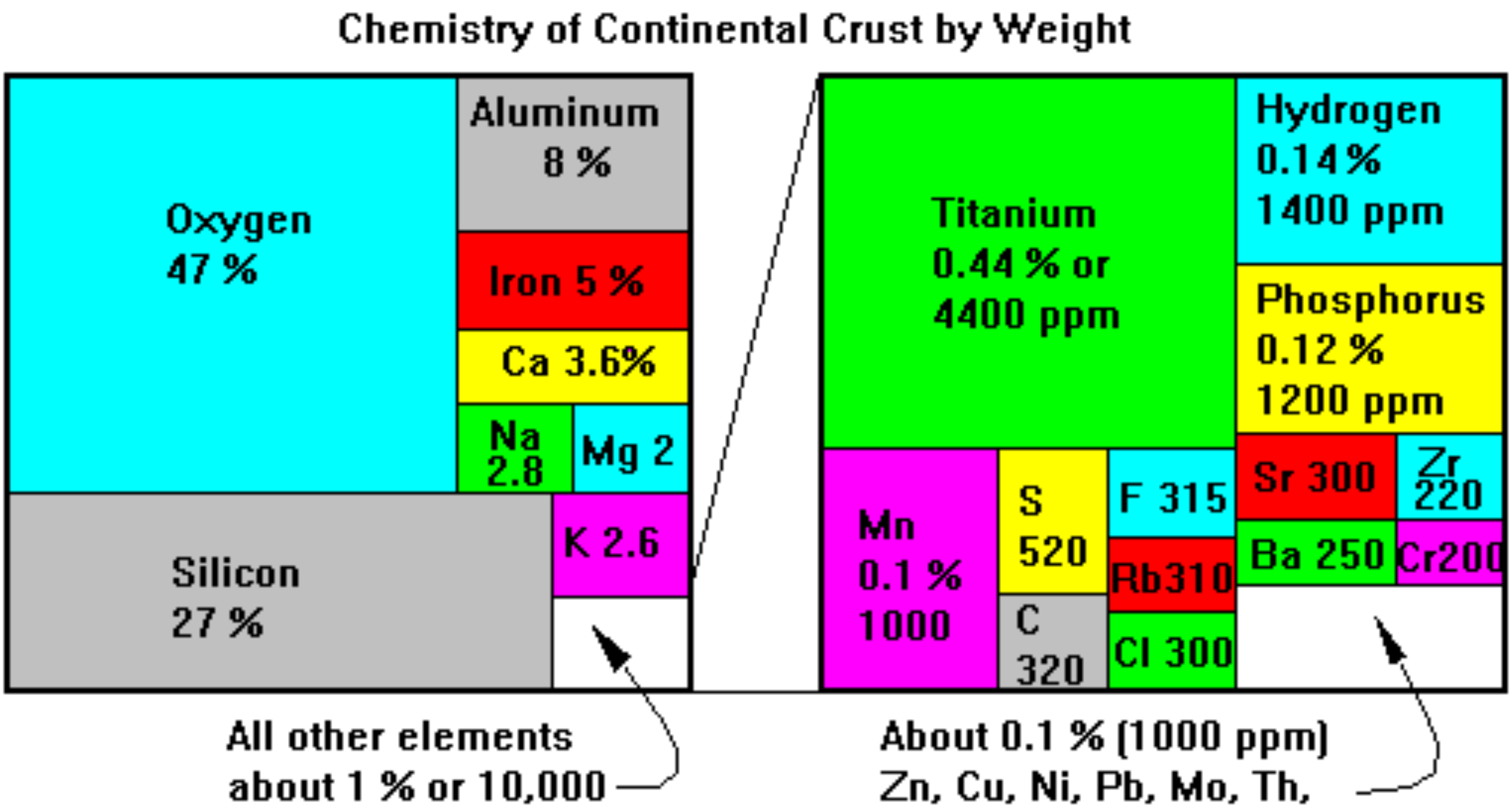
TiO_2 MnO P_2O_5 CO_2

Trace elements: usually < 0.1%everything else

What processes concentrate the trace elements?

This slide modified from: www.whitman.edu/geology/winter/ Petrology/Ch%2008%20Major%20Elements.ppt

What processes extract trace elements from the mantle?
What geologic processes further increase their concentration?



http://www.uwgb.edu/dutchs/Graphics-Geol/rockmin/ccrustwt.gif

What processes alter crustal composition?

Take minute and write down one to three processes.

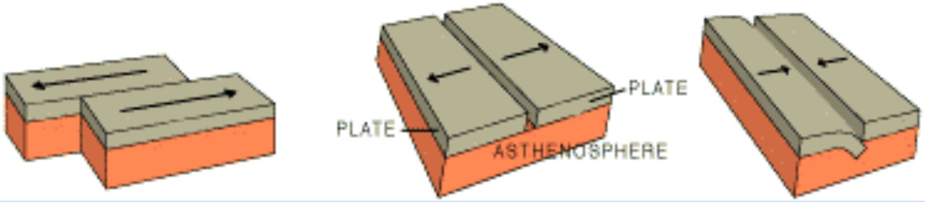
Yes, you didn't come to class, so try to do this before going on.

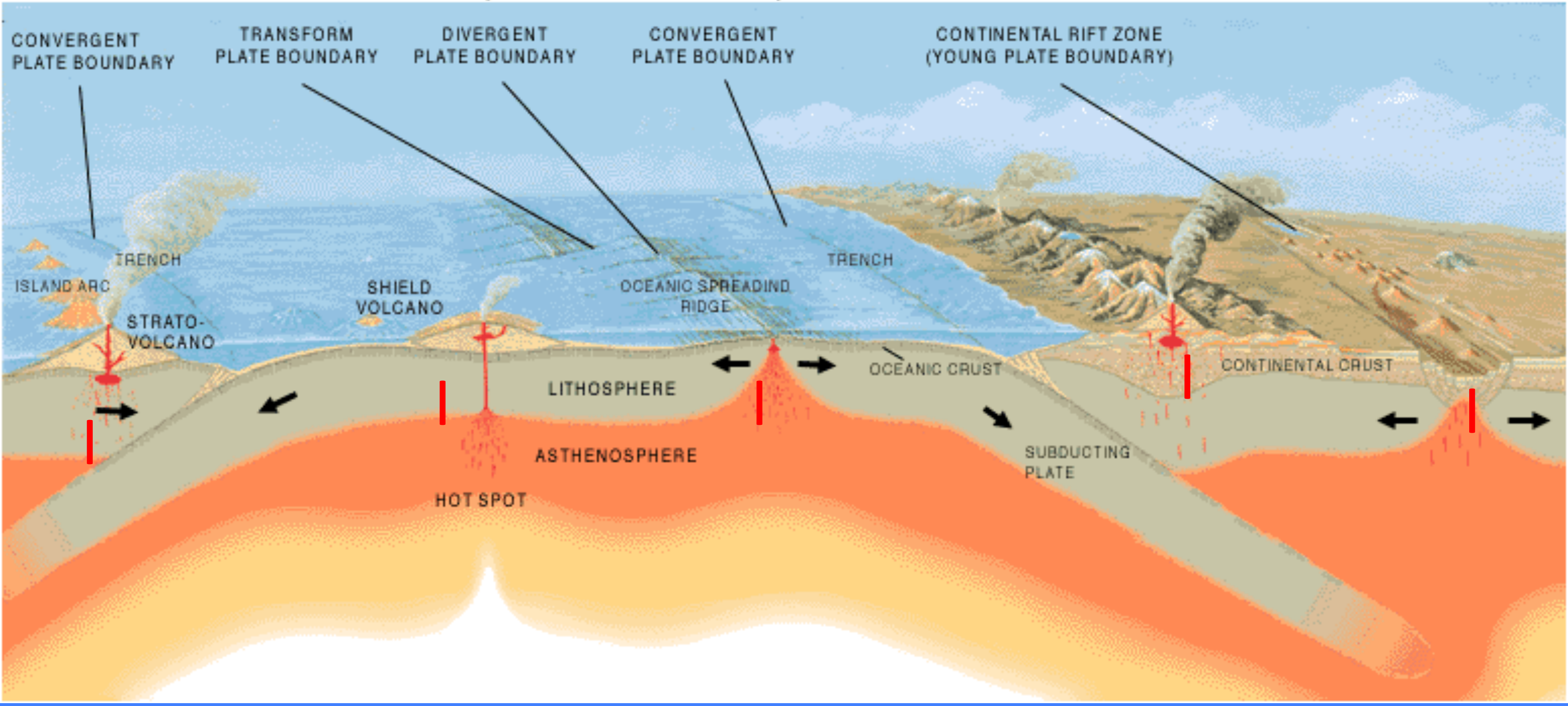
What processes alter crustal composition?

- Magmatism: yields igneous rocks
- Sedimentation: yields sedimentary rocks
- Metamorphism: yields metamorphic rocks

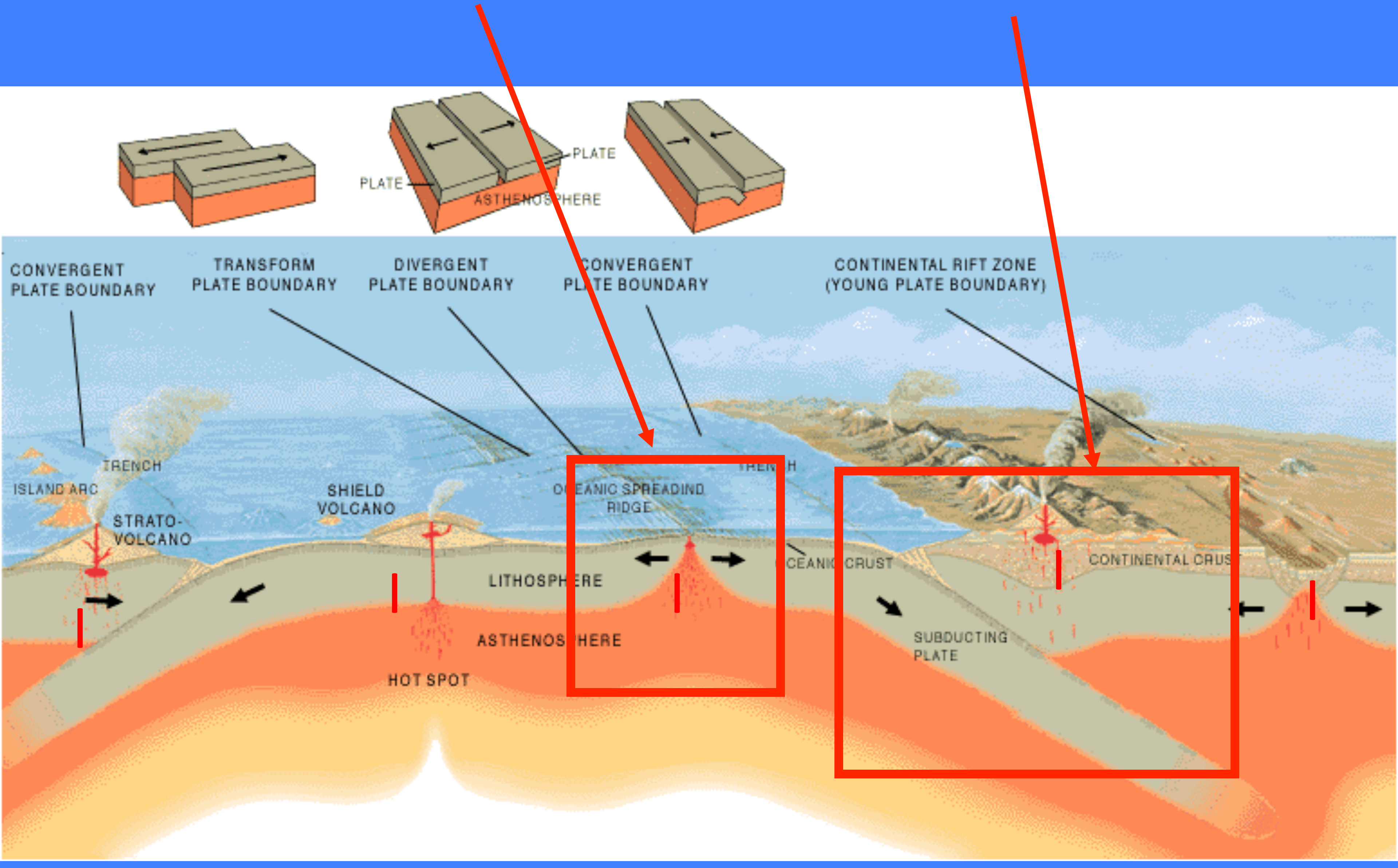
The following slides show where these processes occur on a model of the Earth's tectonic plates. There are also some slides showing the chemistry of typical rocks.

The beginning: How and where do we make igneous rocks?





What is a mid-ocean ridge? What is a subduction zone?
Take a minute to write down whatever comes to mind



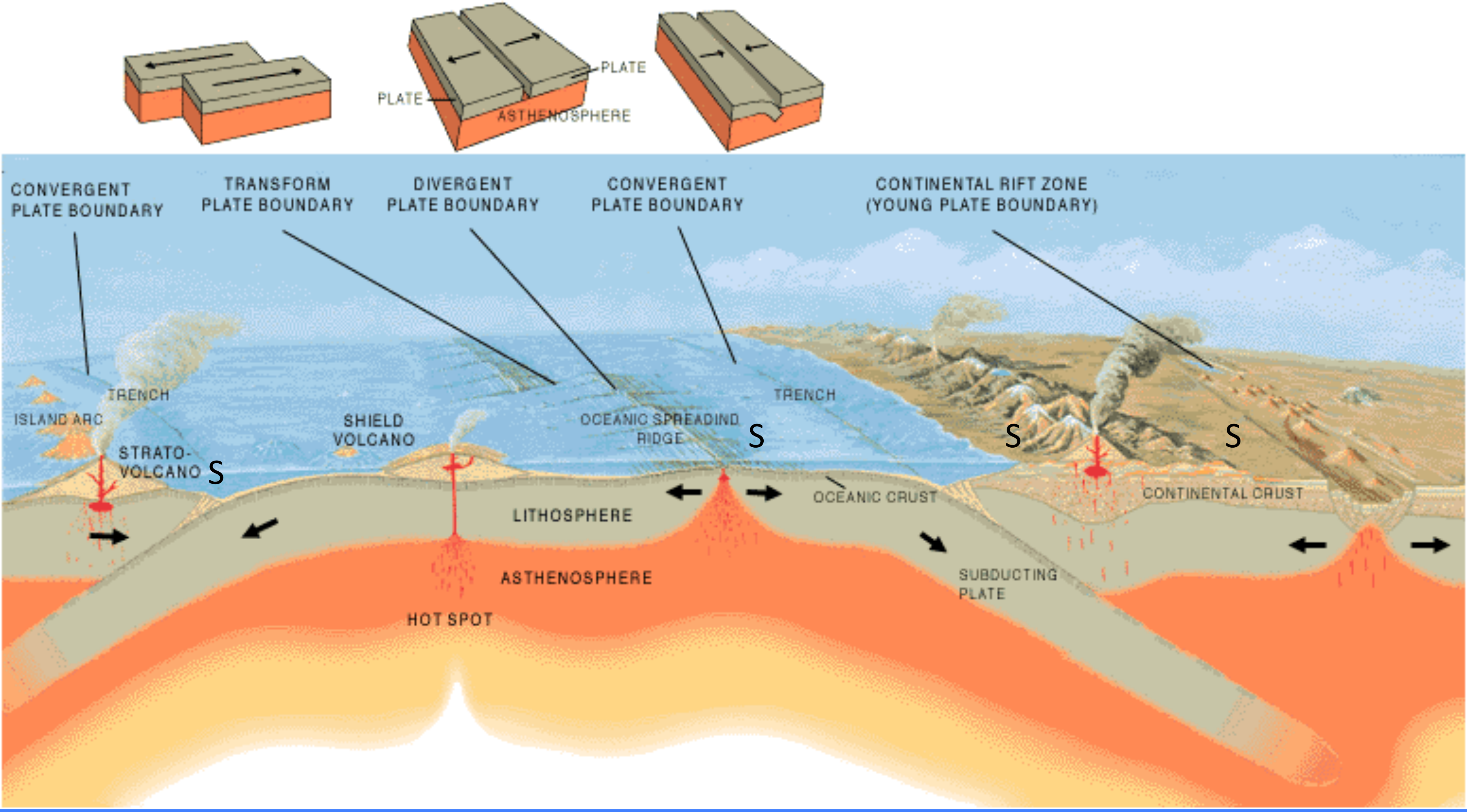
Magmatism produces these major element averages:

Chemical analyses of some representative Igneous Rocks

	Ultra-Basic	Basic	Intermed	Felsic	Intermed
	Peridotite	Basalt	Andesite	Rhyolite	Phonolite
SiO_2	42.26	49.20	57.94	72.82	56.19
TiO_2	0.63	1.84	0.87	0.28	0.62
Al_2O_3	4.23	15.74	17.02	13.27	19.04
Fe_2O_3	3.61	3.79	3.27	1.48	2.79
FeO	6.58	7.13	4.04	1.11	2.03
MnO	0.41	0.20	0.14	0.06	0.17
MgO	31.24	6.73	3.33	0.39	1.07
CaO	5.05	9.47	6.79	1.14	2.72
Na_2O	0.49	2.91	3.48	3.55	7.79
K_2O	0.34	1.10	1.62	4.30	5.24
H_2O^+	3.91	0.95	0.83	1.10	1.57
Total	98.75	99.06	99.3	99.50	99.23

This slide from: www.whitman.edu/geology/winter/ Petrology/Ch%2008%20Major%20Elements.ppt

How and where do we make sedimentary rocks?



Four Carbonates

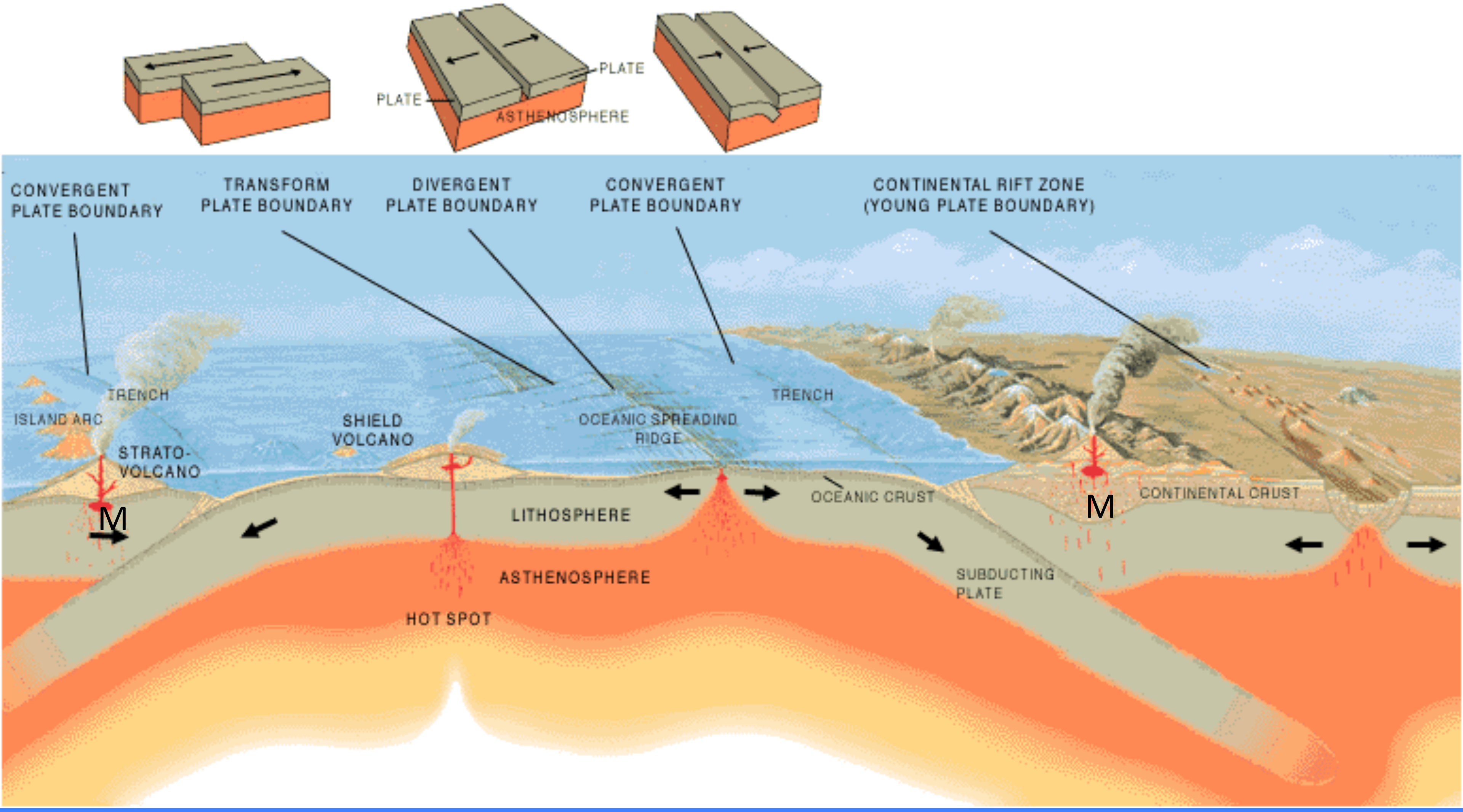
	1	2	3	4
CaO (%)	≤29.00	≤53.00	≤49.00	≤50.00
MgO (%)	≤18.00	≥1.00	≥2.00	≥1.00
SiO_2 (%)	≥2.50	≥1.50	≥2.50	≥2.00
R_2O_3 (%)	≥2.00	≥1.50	≥2.50	≥3.50
S (%)	≥0.050	≥0.030	≥0.050	≥0.025
P (%)	≥0.010	≥0.010	≥0.030	≥0.010
R_2O (%)	≥0.10	≥0.10	≥0.10	≥0.10
H_2O (%)	≥2.00	≥2.00	≥2.00	≥2.00
Sp. area (m^2/g)	1.02	0.271	7.3	2.00
Porosity (%)	5.04	4.75	30.82	12.1

Some Estonia Sandstones

Table 66. Chemical composition of the sandstone of the Tiskre Formation (Чехомский и Пальмре **1960**)

Location	Content of components				
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO
Saka	96.81-99.40	0.53-1.69	0.05-0.09	0.15-0.22	-0.36
Kunda	96.69-98.80	0.58-0.81	0.13-0.20	0.46	
Aseri	98.08	0.36	0.18	-	0.41

How and where do we make metamorphic rocks?



0.3.3 The chemical composition of metamorphic rocks — Die chemische Zusammensetzung der Metamorphite

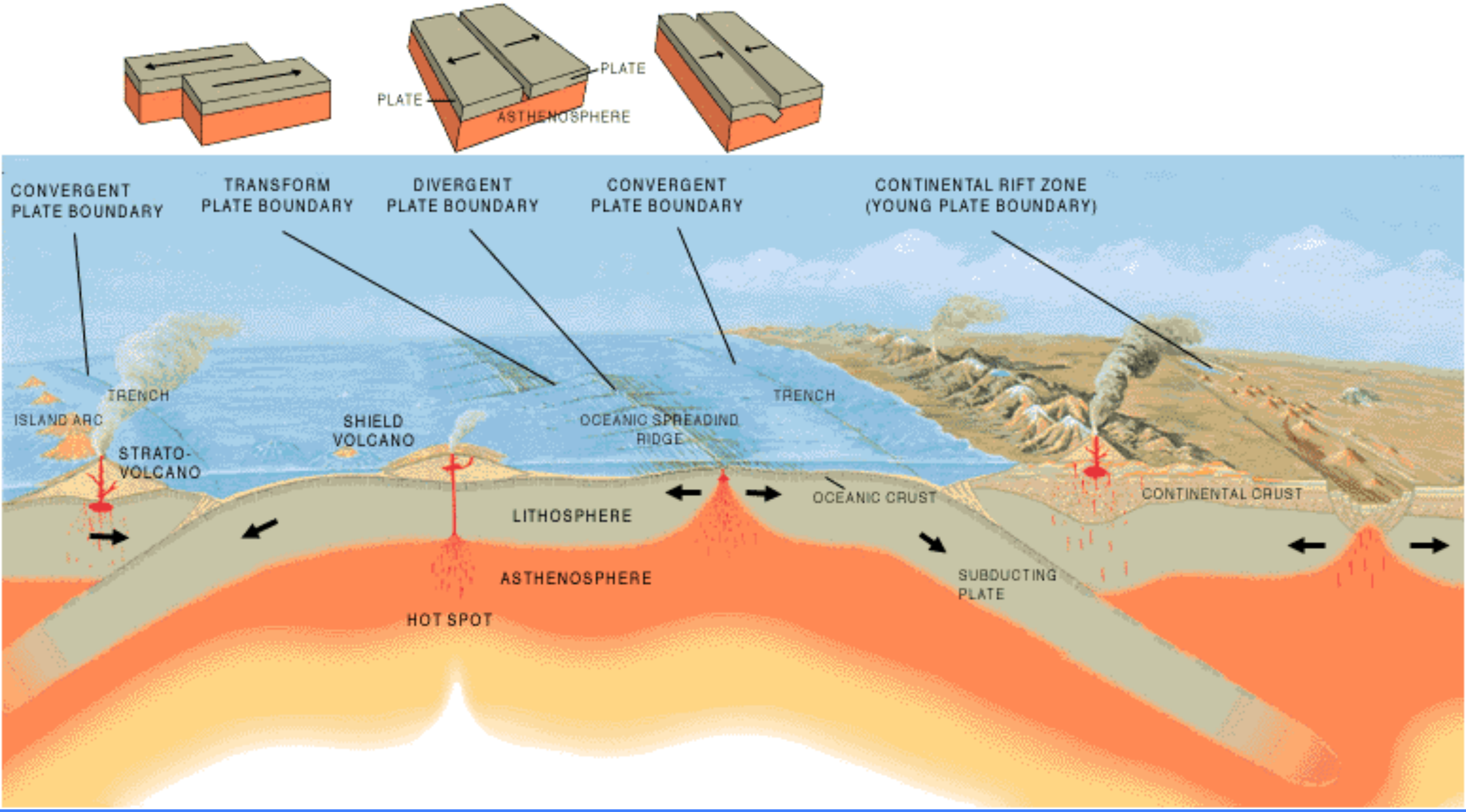
Text: see p. 34

Table 13. Selected chemical compositions of common metamorphic rocks. For comparison with igneous and sedimentary rocks the CIPW-norm or normative composition is given.

	Phyllite, Furulund, Norway [Cor68]	Phyllite, Grand Paradise, France [Cor68]	Pelitic schist, Vermont [Mue77]	Actinolite-albite-epidote, Agnew Lake, Ontario [Mue77]	Pelitic schist, Agnew Lake, Ontario [Mue77]	Magnetic-hematite-bearing pelitic gneiss, Glen Clova, Scotland [Mue77]	Plagioclase-quartz-biotite gneiss, West Balmat, New York [Mue77]	Pyroxene gneiss, Lützow Holm Bay, Antarctica [Mue77]	Staurolite-garnet-plagioclase gneiss, Spessart, Germany [Cor68]	Kyanite-andalusite-sillimanite gneiss, Idaho [Mue77]	Amphibolite, Adirondack, New York [Mue77]
	wt-%										
SiO_2	49.22	47.50	39.41	55.07	48.60	44.09	67.92	56.81	58.71	48.20	48.20
TiO_2	0.18	2.25	0.66	0.98	0.32	1.69	0.70	1.01	0.83	0.14	1.89
Al_2O_3	18.56	18.79	31.21	21.50	9.16	23.64	15.53	17.33	20.78	32.54	14.45
Fe_2O_3	2.22	4.65	2.10	2.72	4.65	12.01	0.77	1.87	4.24	0.23	3.50
FeO	5.35	6.30	10.36	6.04	6.48	3.66	3.51	5.55	3.46	2.24	10.53
MnO	0.12	0.10	0.16	0.05	0.25	0.37	0.05	0.13	0.18	0.05	0.25
MgO	8.15	5.92	3.41	3.00	18.41	2.61	2.04	3.46	2.56	9.30	6.62
CaO	7.17	7.68	0.14	0.98	9.57	0.85	2.22	6.55	1.15	0.84	10.25
Na_2O	4.65	3.76	1.55	1.43	0.53	2.03	3.90	3.54	1.65	1.66	1.94
K_2O	0.10	0.30	4.01	3.01	0.20	6.01	2.67	2.24	4.05	2.32	0.96
H_2O^+	3.15	1.12	6.54	3.53	1.29	3.09	0.72	0.85	1.70	2.26	1.31
H_2O^-				0.02		0.12		0.14		0.12	0.01
P_2O_5	n.d.	0.46		0.11	0.03	0.15	0.11	0.26	0.24	0.01	0.18
CO_2	0.43	1.50		0.12	0.07					0.22	
F							0.07				
S		0.02									
normative composition	wt-%										
qz (quartz)		2.7	2.2	26.3		4.0	25.5	7.2	27.3	12.9	0.3
cor (corundum)		2.9	24.2	14.9		12.6	2.6		12.2	26.3	
or (K-feldspar)	0.6	1.8	23.8	18.0	1.2	35.4	15.7	13.3	24.0	13.7	5.7
ab (albite)	39.6	31.7	13.2	12.3	4.5	17.1	32.9	30.0	14.0	14.0	16.4
an (anorthite)	29.7	25.5	0.7	3.4	22.2	3.3	9.8	24.8	4.2	2.7	27.9
di (diopside)	2.7				19.7			5.0			17.9
hy (hypersthene)	0.3	18.9	2.5	15.0	40.6	6.5	9.8	13.4	8.2	26.9	21.4
ol (olivine)	19.3				3.0						
mt (magnetite)	3.2	6.7	3.1	4.0	6.8	8.1	1.1	2.7	6.2	0.3	5.1
hm (hematite)						6.4					
ilm (ilmenite)	0.3	4.3	1.3	1.9	0.61	3.2	1.3	1.9	1.6	0.2	3.6
ap (apatite)		1.1		0.3	0.1	0.4	0.3	0.6	0.6		0.4
ce (calcite)	1.0	3.4		0.3	0.2					0.5	
ne (nepheline)											

Huckenholz

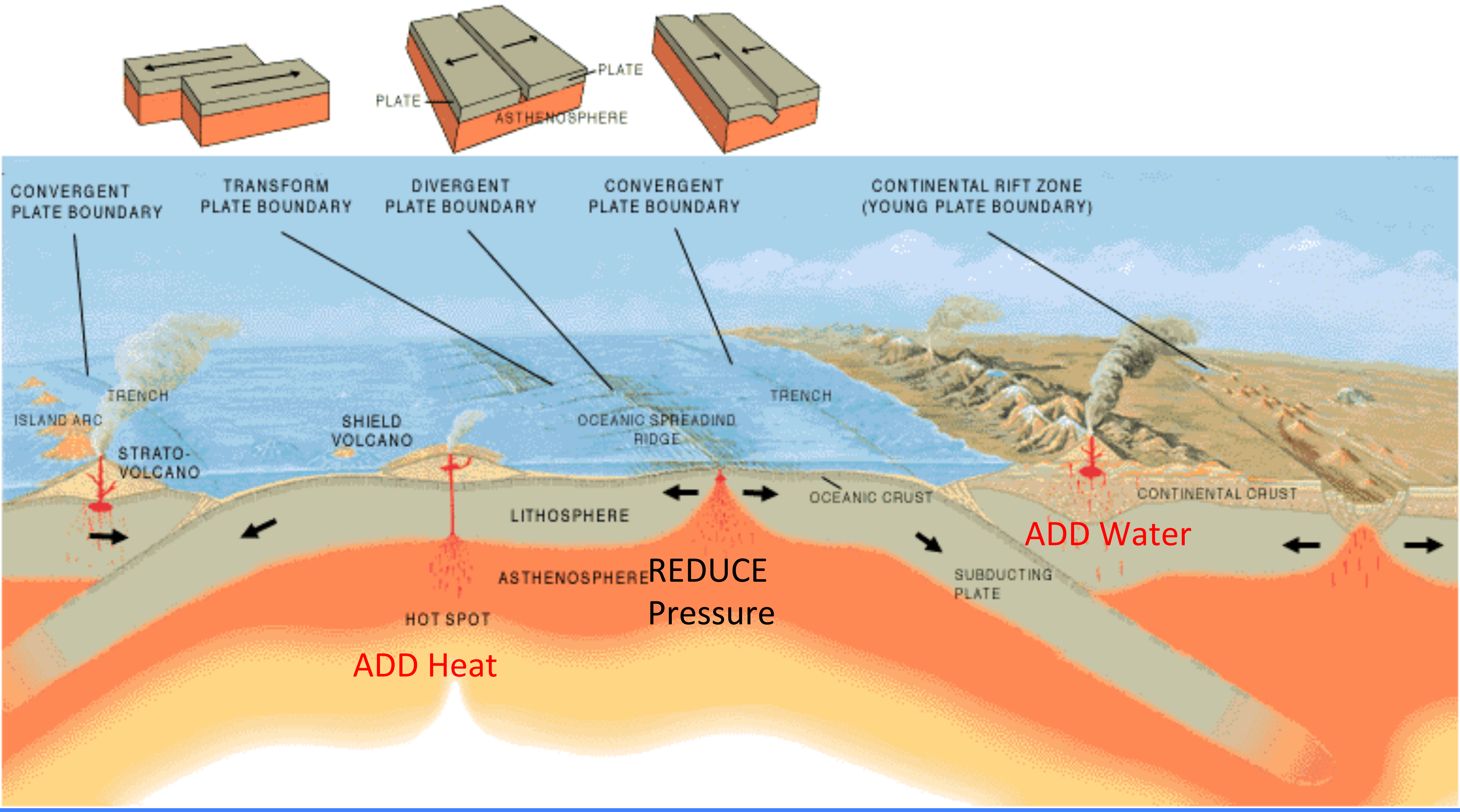
How and where do we make igneous rocks?



Magmatism begins with PARTIAL MELTING of the mantle

Magmatism begins with PARTIAL MELTING of the mantle.

It is easy: the mantle is very close to its partial melting point.



You're almost done. Just one more slide about the origin of igneous rocks through magmatism.

Magmatism produces these major element averages:

Chemical analyses of some representative Igneous Rocks

	Ultra-Basic	Basic	Intermed	Felsic	Intermed
	Peridotite	Basalt	Andesite	Rhyolite	Phonolite
SiO2	42.26	49.20	57.94	72.82	56.19
TiO2	0.63	1.84	0.87	0.28	0.62
Al2O3	4.23	15.74	17.02	13.27	19.04
Fe2O3	3.61	3.79	3.27	1.48	2.79
FeO	6.58	7.13	4.04	1.11	2.03
MnO	0.41	0.20	0.14	0.06	0.17
MgO	31.24	6.73	3.33	0.39	1.07
CaO	5.05	9.47	6.79	1.14	2.72
Na2O	0.49	2.91	3.48	3.55	7.79
K2O	0.34	1.10	1.62	4.30	5.24
H2O+	3.91	0.95	0.83	1.10	1.57
Total	98.75	99.06	99.3	99.50	99.23
	~Mantle	Partial Melts of the Mantle			

This slide from: www.whitman.edu/geology/winter/ Petrology/Ch%2008%20Major%20Elements.ppt