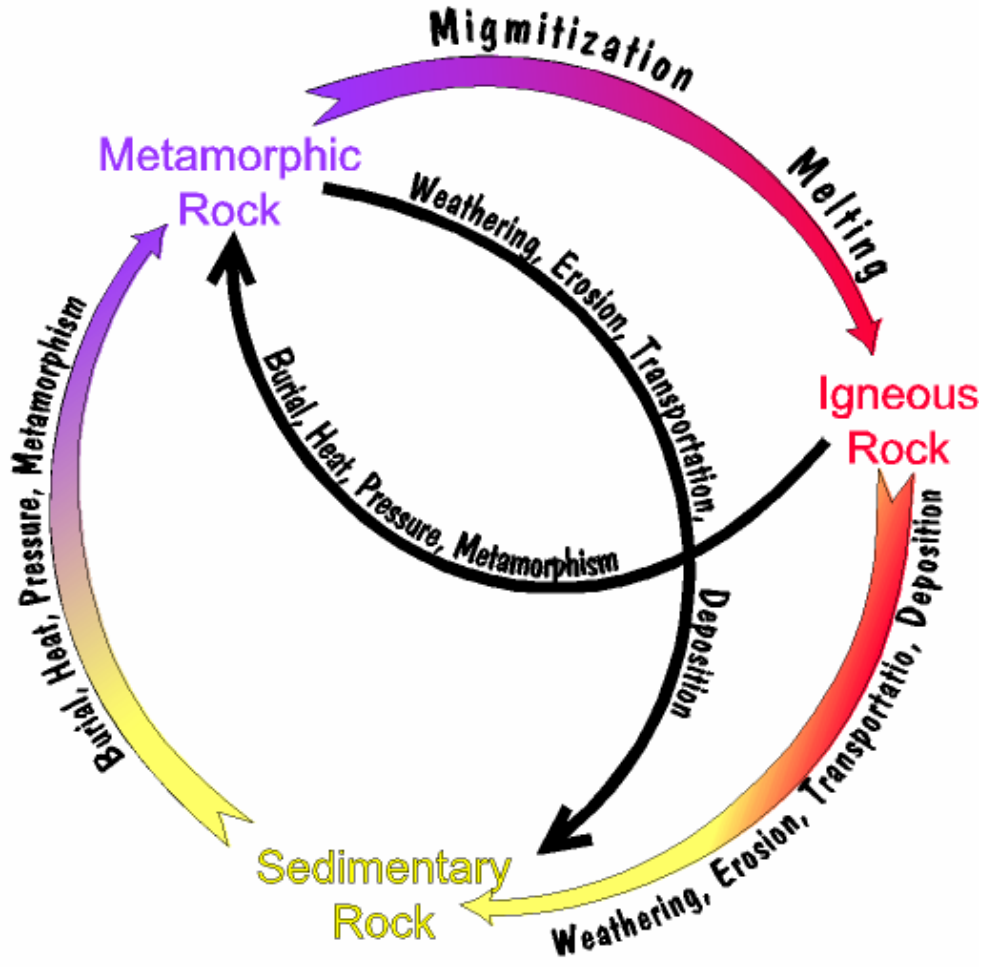
The Wilson Cycle

The Opening and Closing of An Ocean Basin

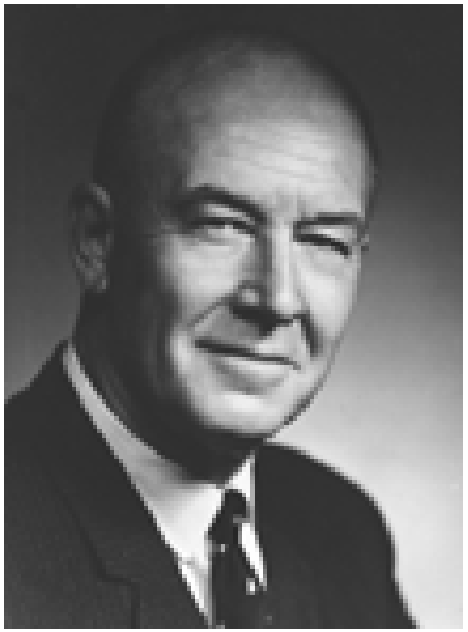
The Rock Cycle



The rock cycle says all rocks can be transformed into other rocks, but the important question is, under what conditions.

Wilson Cycles

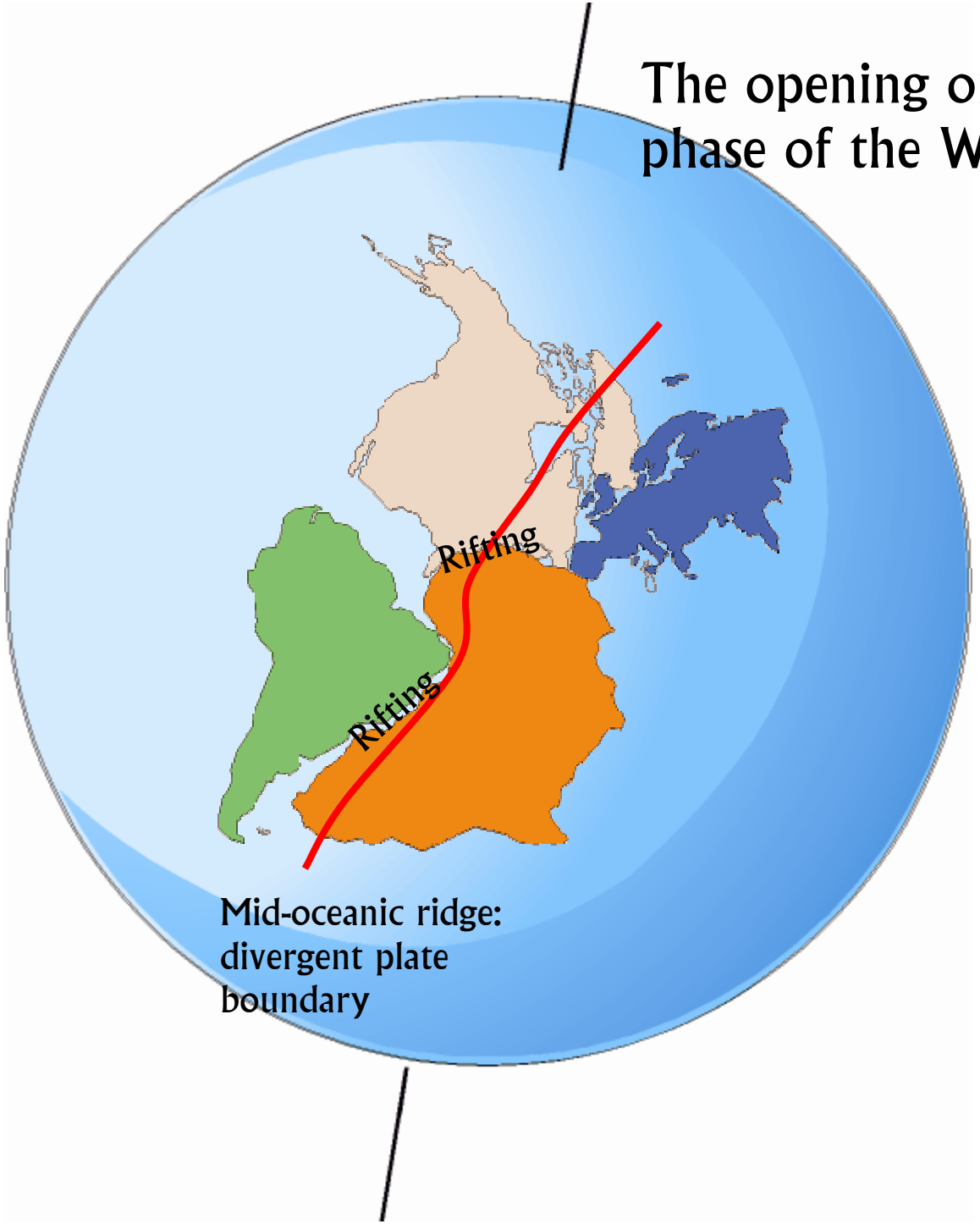
The Opening and Closing of An Ocean Basin



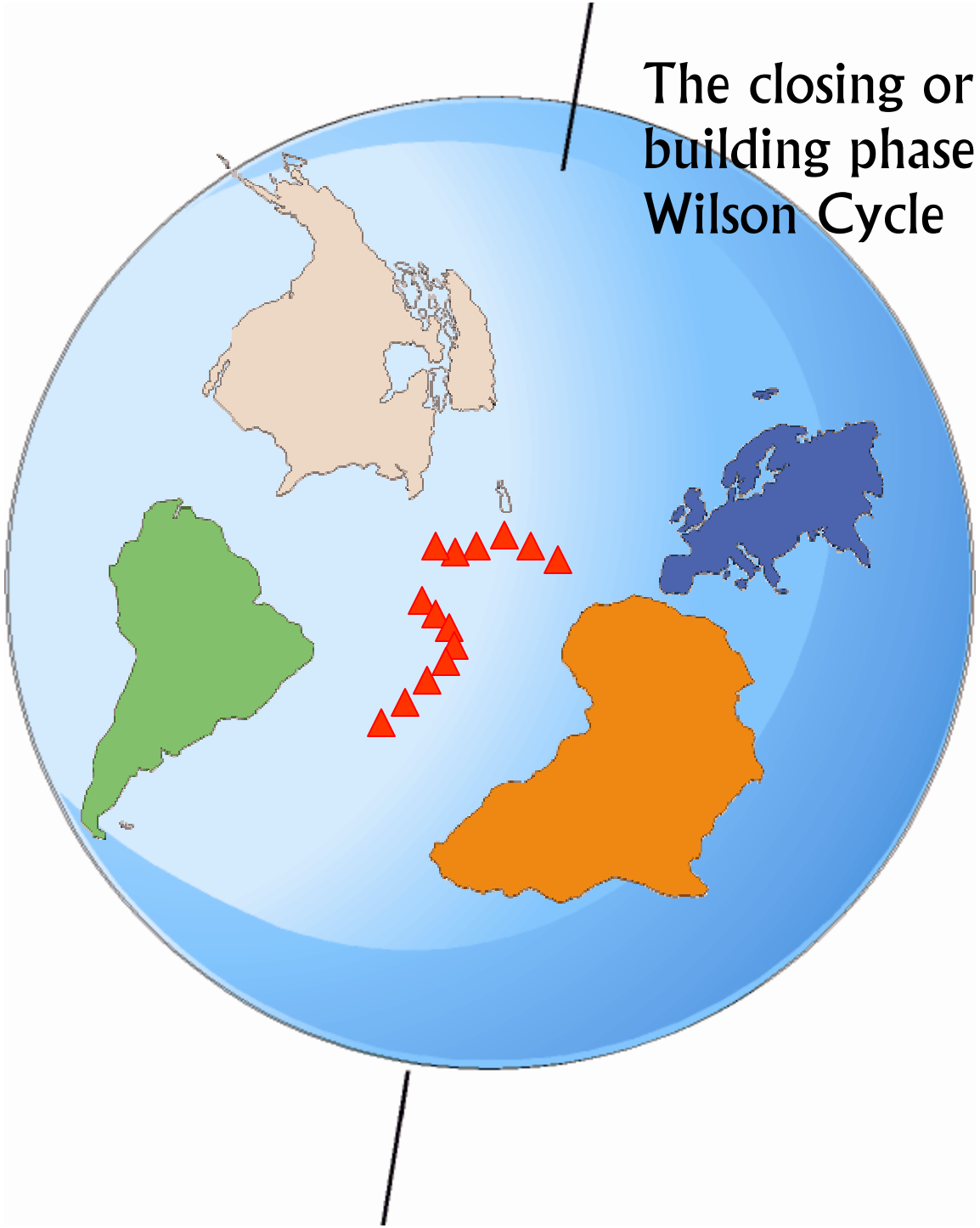
Wilson, J.T., 1966, Did the Atlantic close and then reopen? Nature, v. 211, p. 676-681.

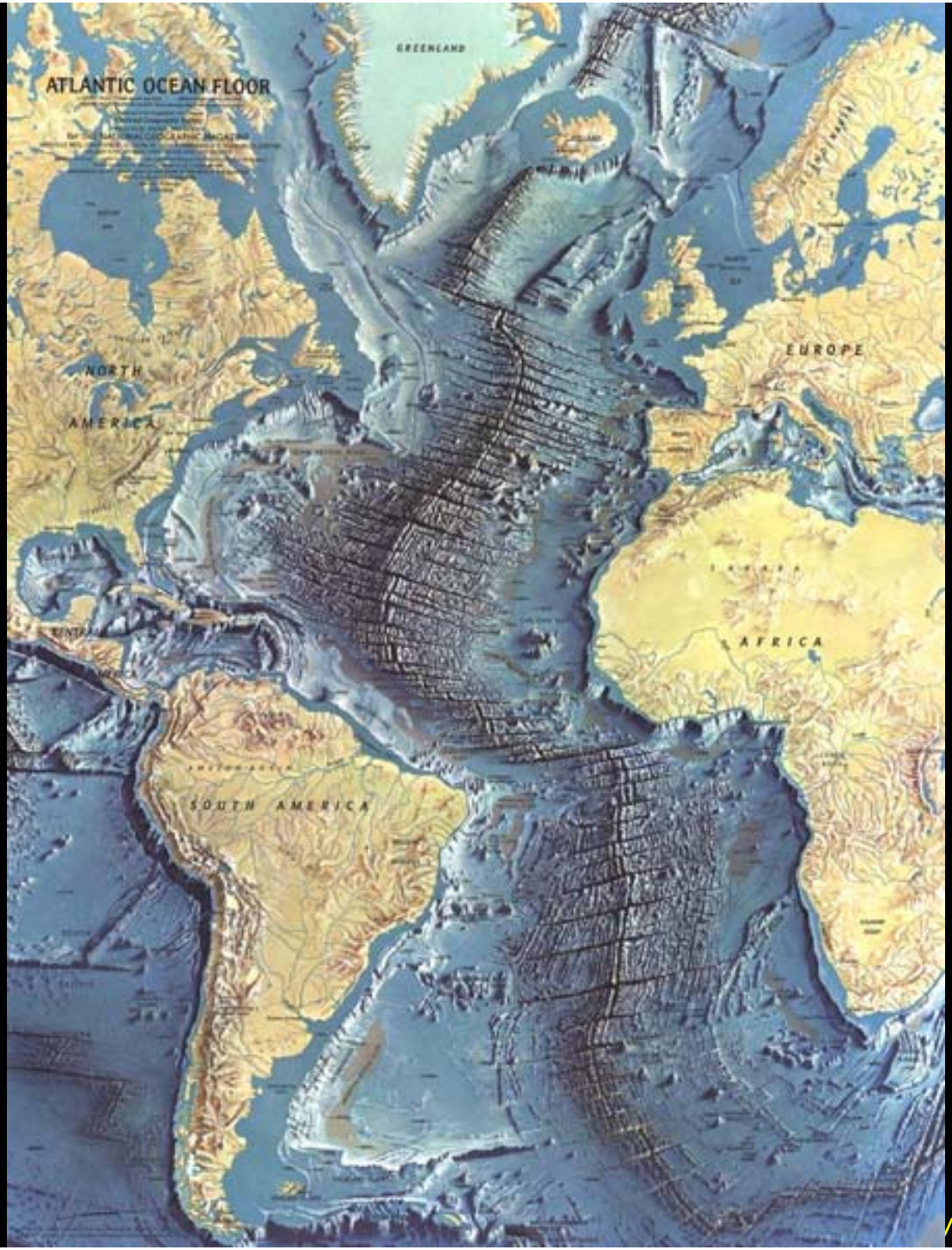
born Ottawa, Ontario, October 24, 1908; died April 15, 1993. Ph.D., 1936, Princeton Univ.

The opening or rifting phase of the Wilson Cycle

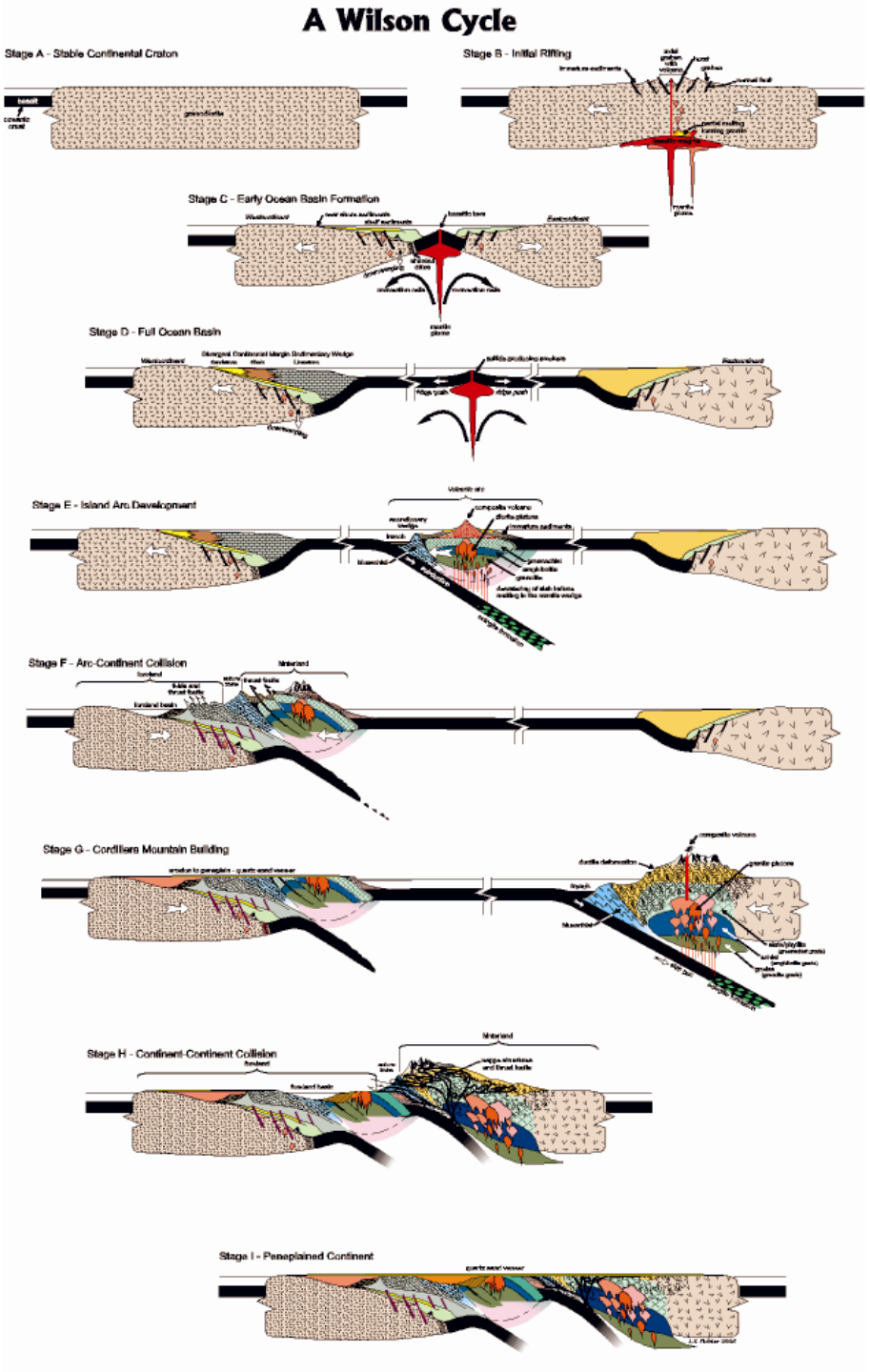


The closing or mountain building phase of the Wilson Cycle





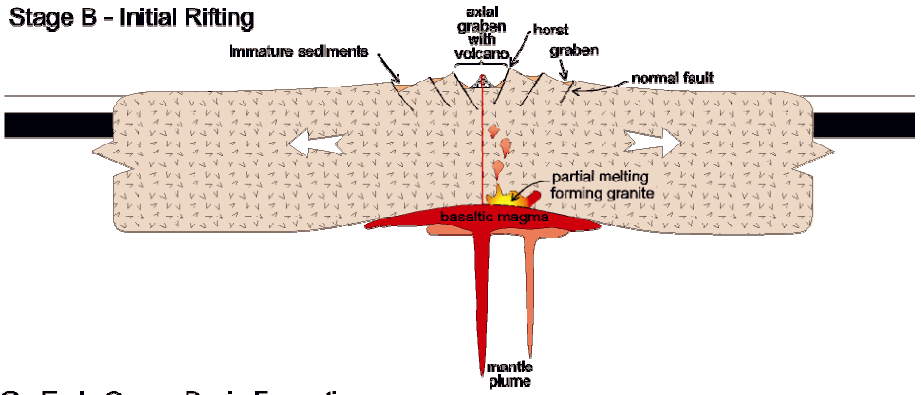
The simple ideal model of tectonic evolution



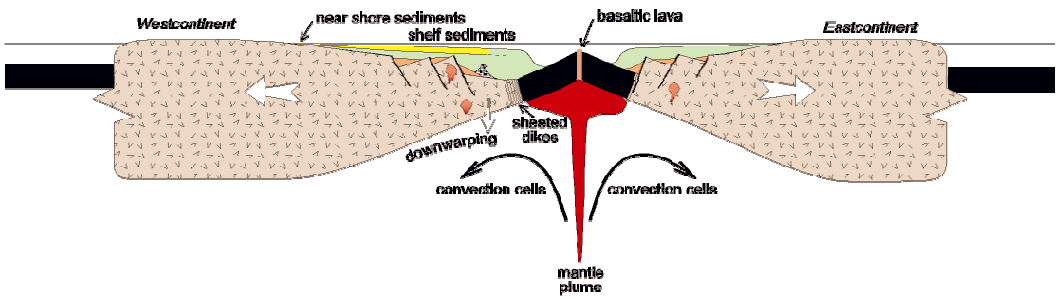
Wilson Cycle – Opening Phase

Stage A - Stable Continental Craton

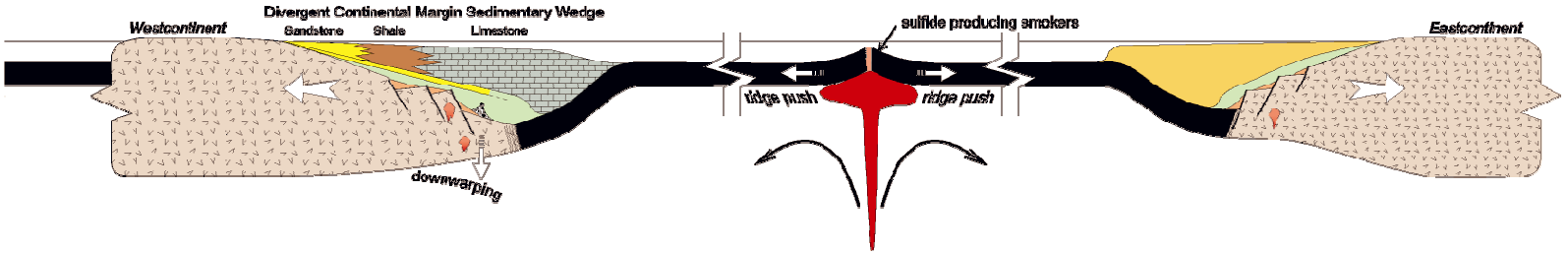
Stage B - Initial Rifting



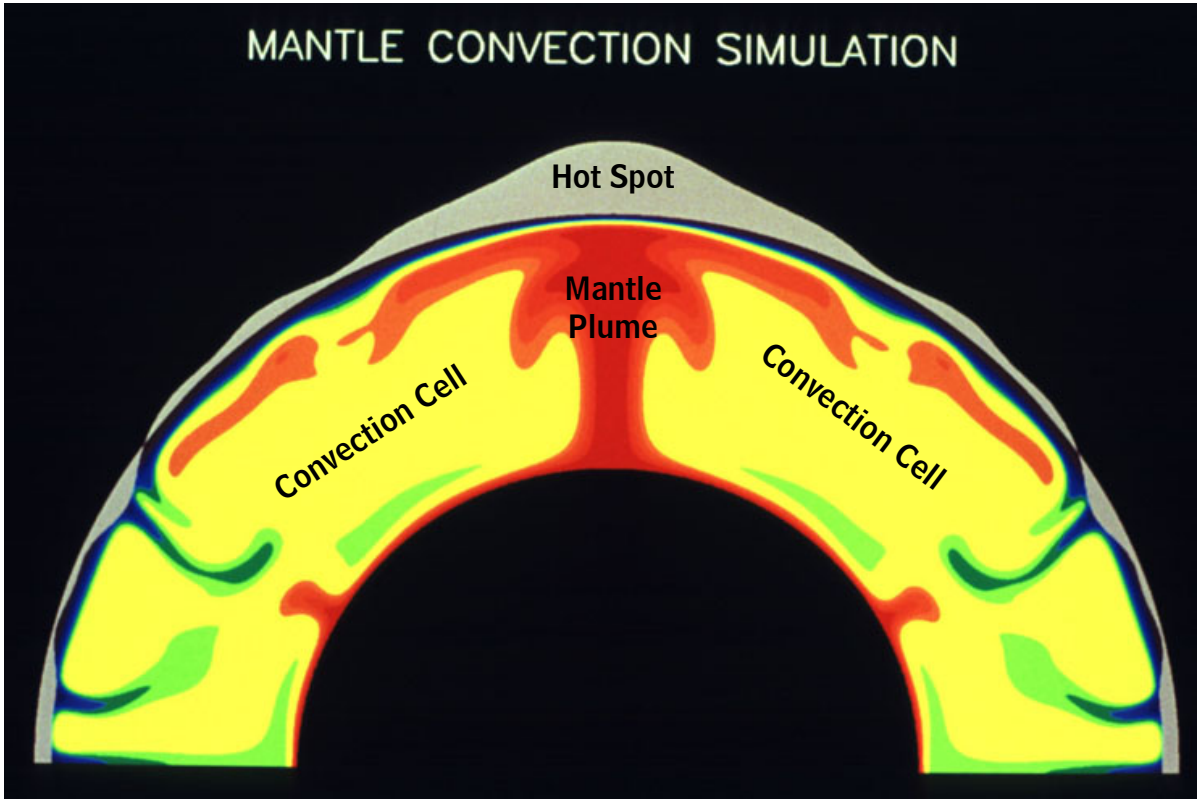
Stage C - Early Ocean Basin Formation



Stage D - Full Ocean Basin



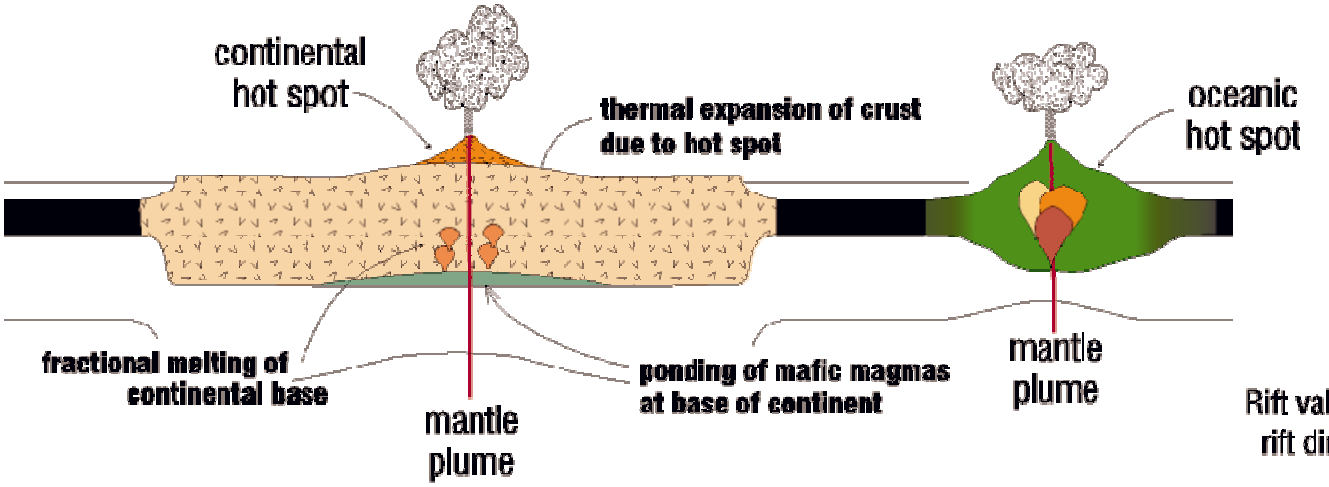
The Rifting Model

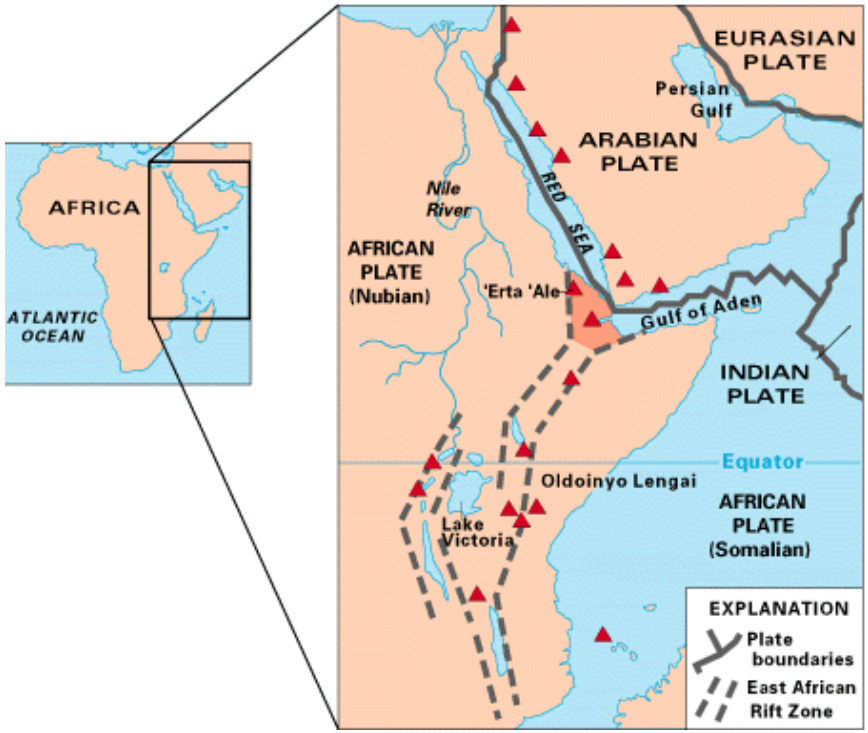


Rifting events and the formation of divergent plate boundaries are driven by mantle convection cells. Where a mantle plume or convection cell rises toward the lithosphere (red zones in the diagram above) heat is transferred to the lithosphere causing it to swell upward into a hot spot. The surface rocks at the hotspot as they stretch upward crack and form normal faults, that develop into a horst and graben system, the beginning of a rifting event.

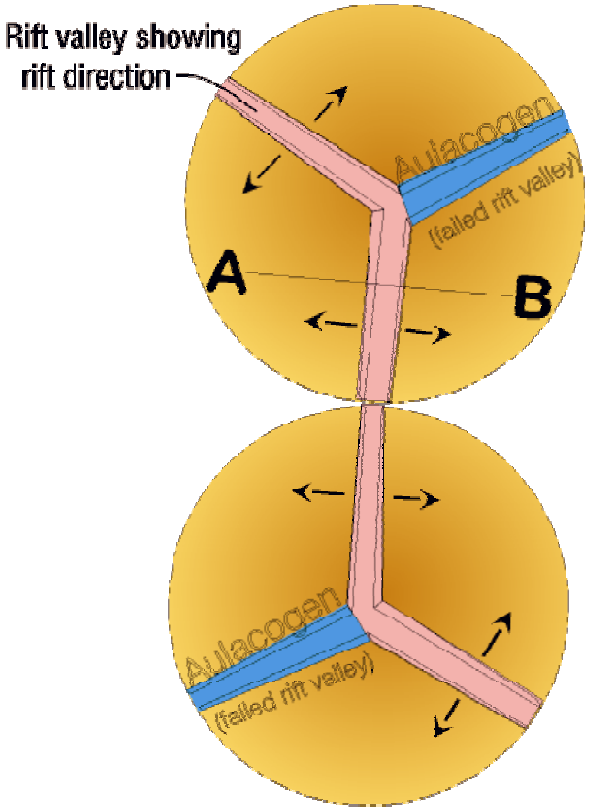
http://fti.neep.wisc.edu/neep602/FALL97/LEC15/lecture15.html

The Rifting Model



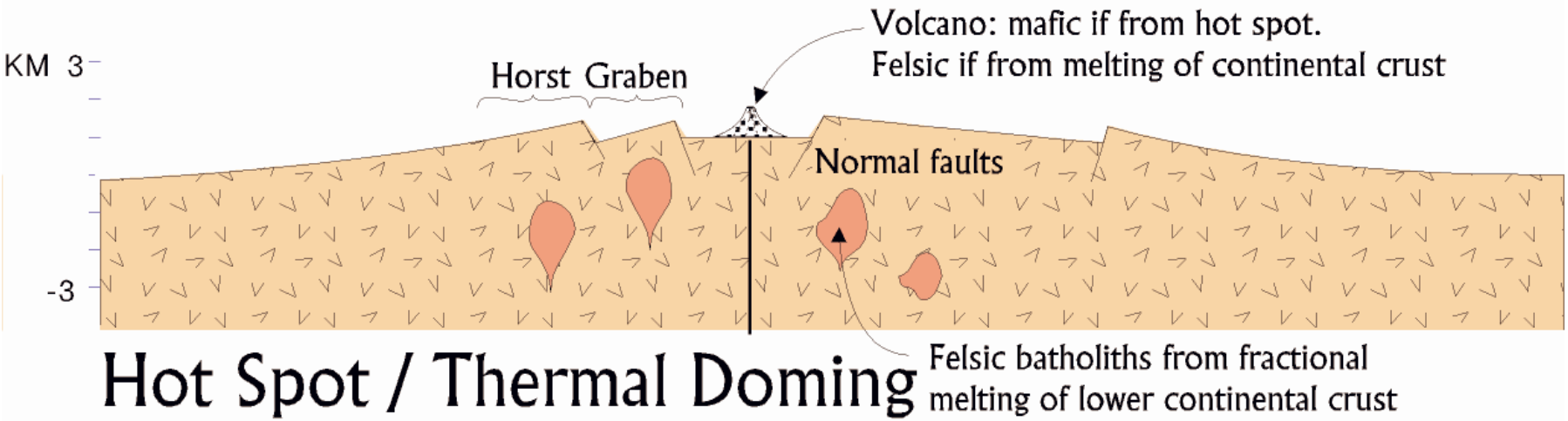


http://pubs.usgs.gov/publications/text/East_Africa.html

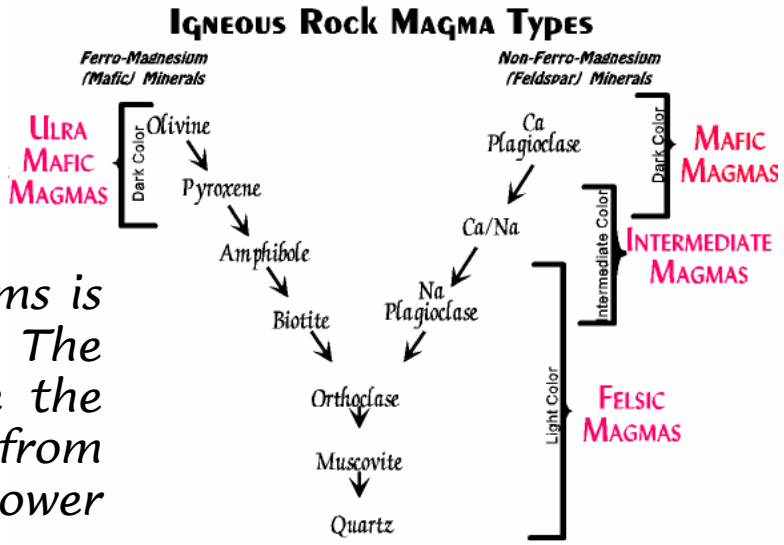


Areal view of two hotspots/triple junctions

The Rifting Model



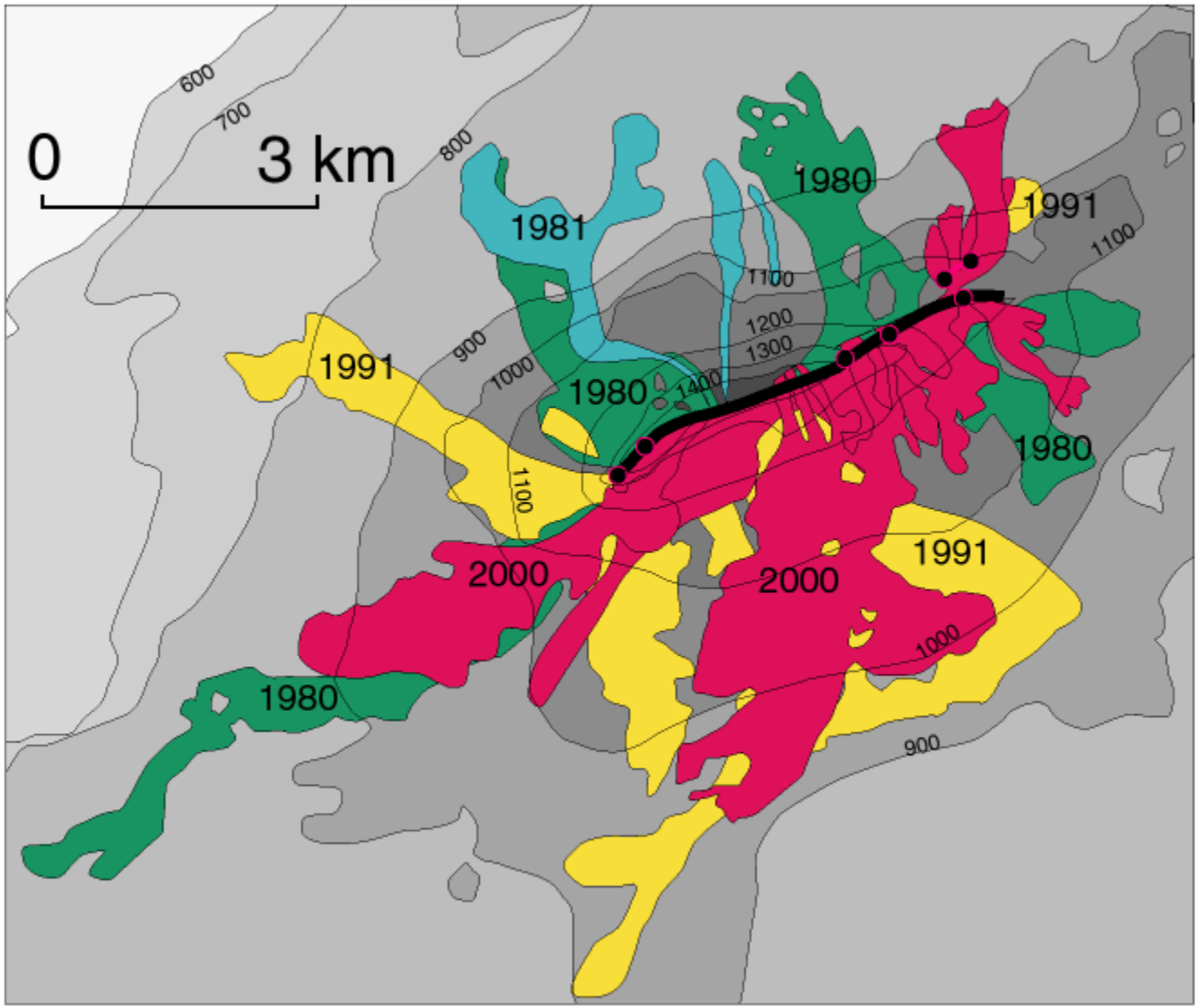
Igneous Activity = Bimodal Association: mafic (tholeiitic) + felsic (alkali)



A characteristic feature of rift systems is the bimodal igneous association. The mafic rocks come from deep inside the earth, while the alkali rocks derive from the fractional melting of the lower portions of the continent.

The Rifting Model

Hekla Iceland Fissure Volcano



http://www.decadevolcano.net/volcanoes/iceland/hekla.htm

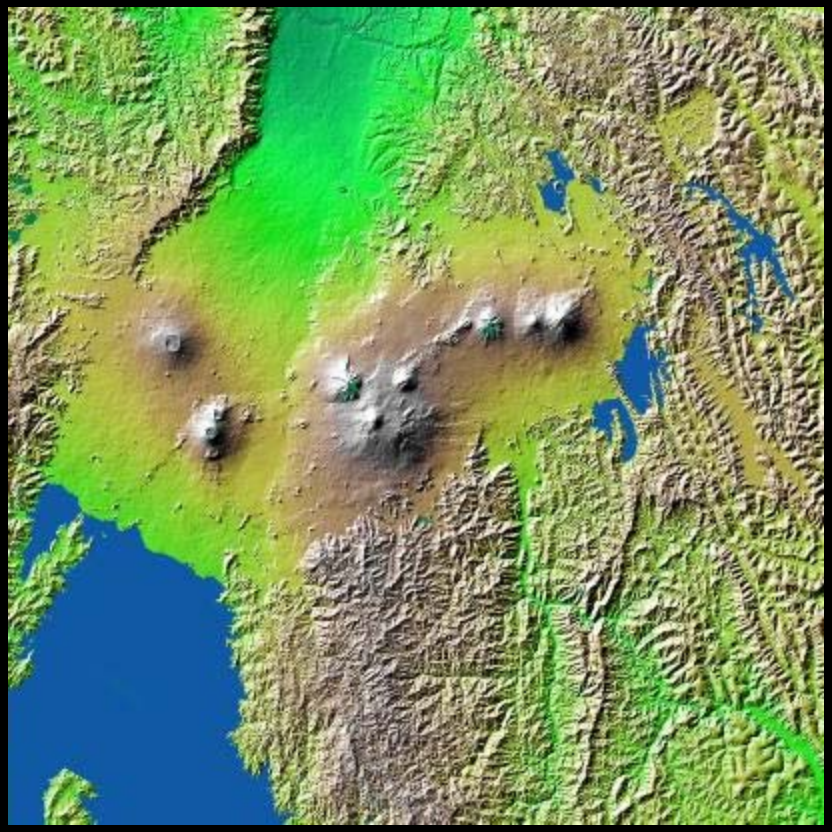
Iceland Fissure Volcano

http://www.decadevolcano.net/volcanoes/iceland/hekla.htm

The Rifting Model

East African Rift in Kenya

East African Rift Volcanoes



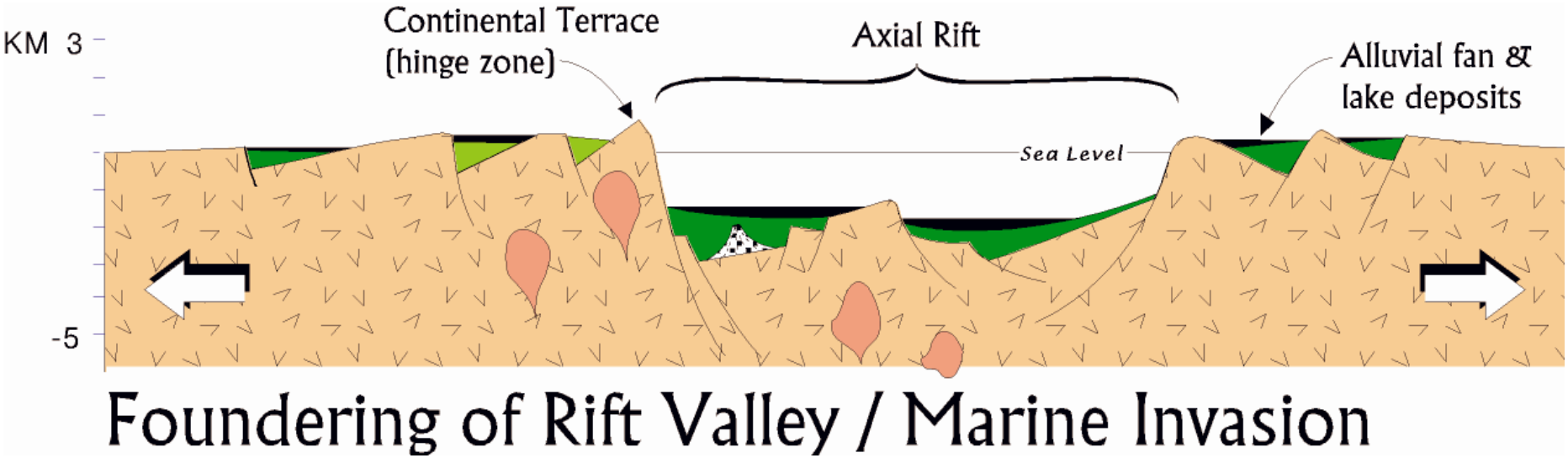
Elevation models of a region along the East African Rift at Lake Kivu.
The area shown covers parts of Congo, Rwanda and Uganda.

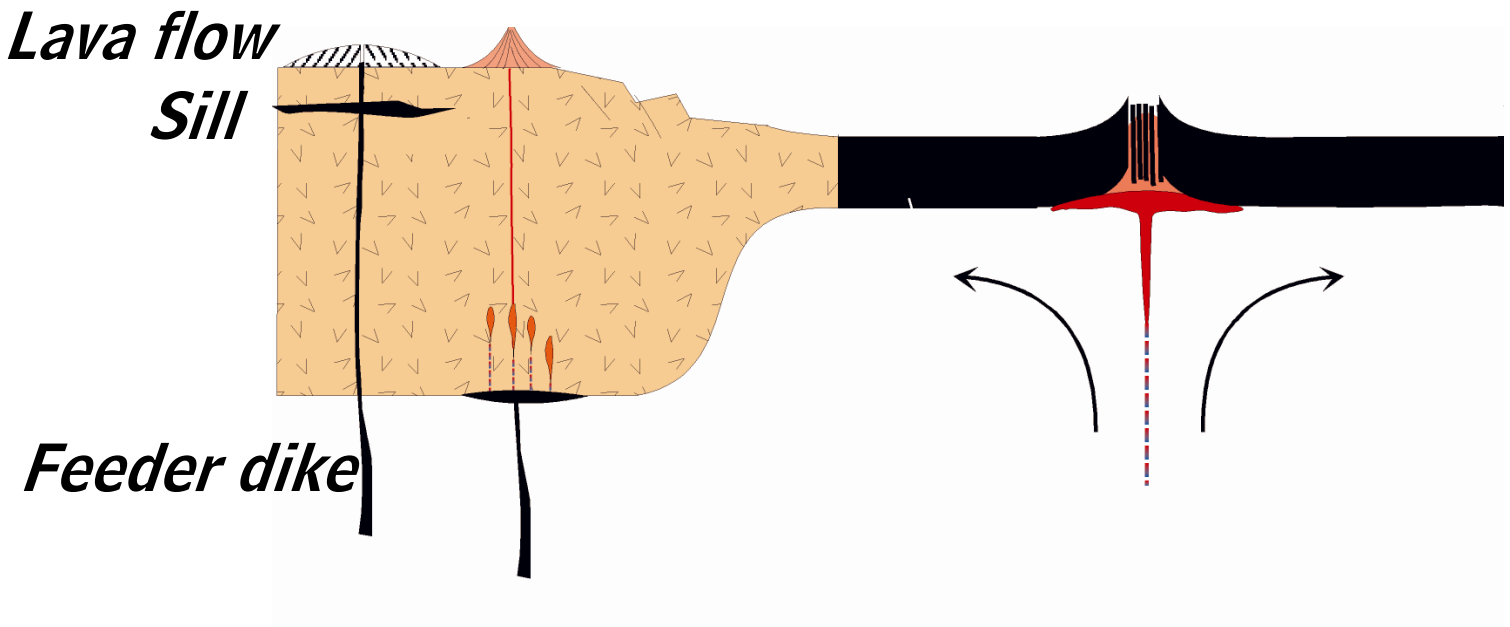
http://photojournal.jpl.nasa.gov/feature/Africa?sort=ASC&start=40&subselect=refine%3Ayes

Cinder Volcanoes in the East African Rift

Cinder Volcanoes in the East African Rift

The Rifting Model



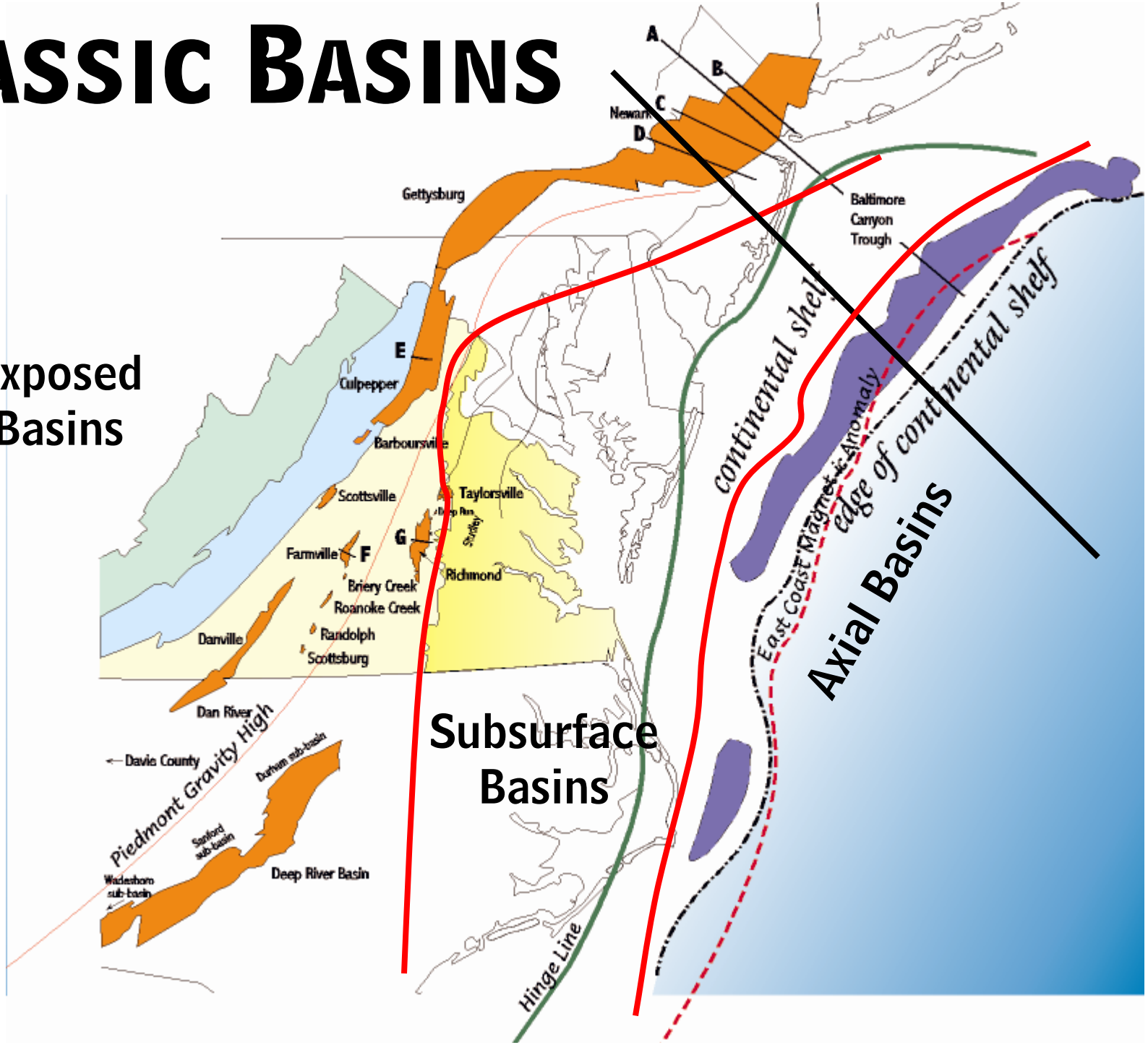


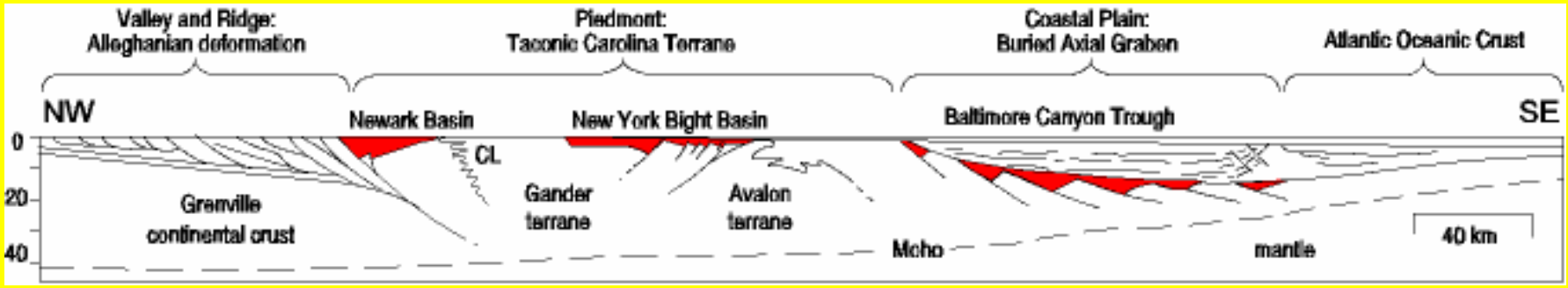
Dike

Discordant

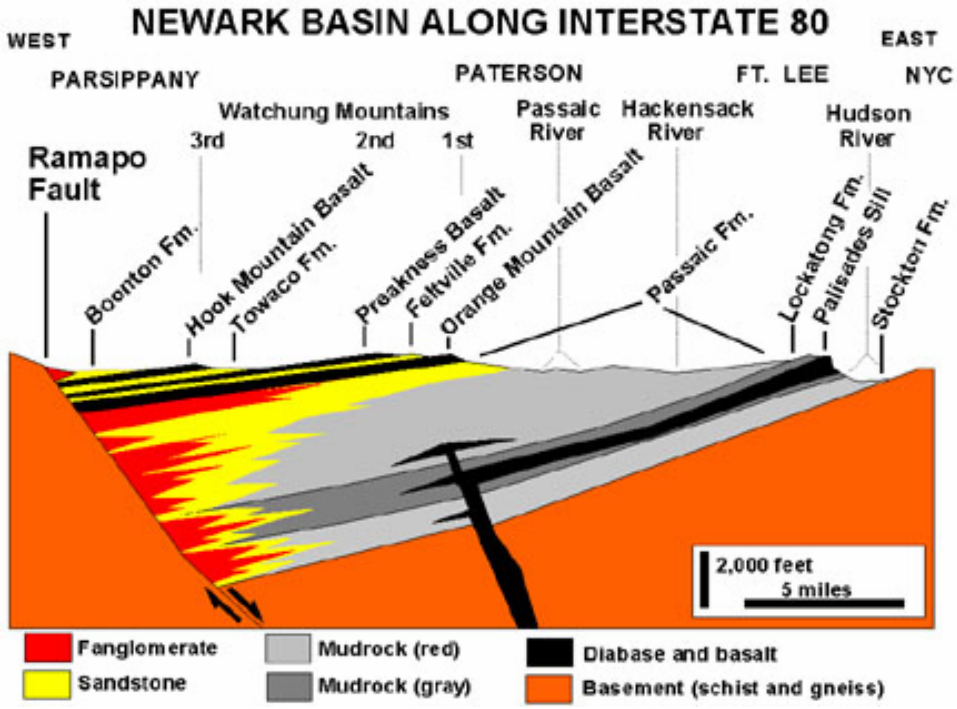
Dike at Old Rag Mountain

Triassic Basins




Valley and Ridge:
Alleghanian deformation
Piedmont:
Taconic Carolina Terrane
Coastal Plain:
Buried Axial Graben
Atlantic Oceanic Crust
NW
SE
Newark Basin
New York Bight Basin
Baltimore Canyon Trough
CL
0
20
40
Grenville
continental crust
Gander
terrane
Avalon
terrane
Moho
mantle
40 km

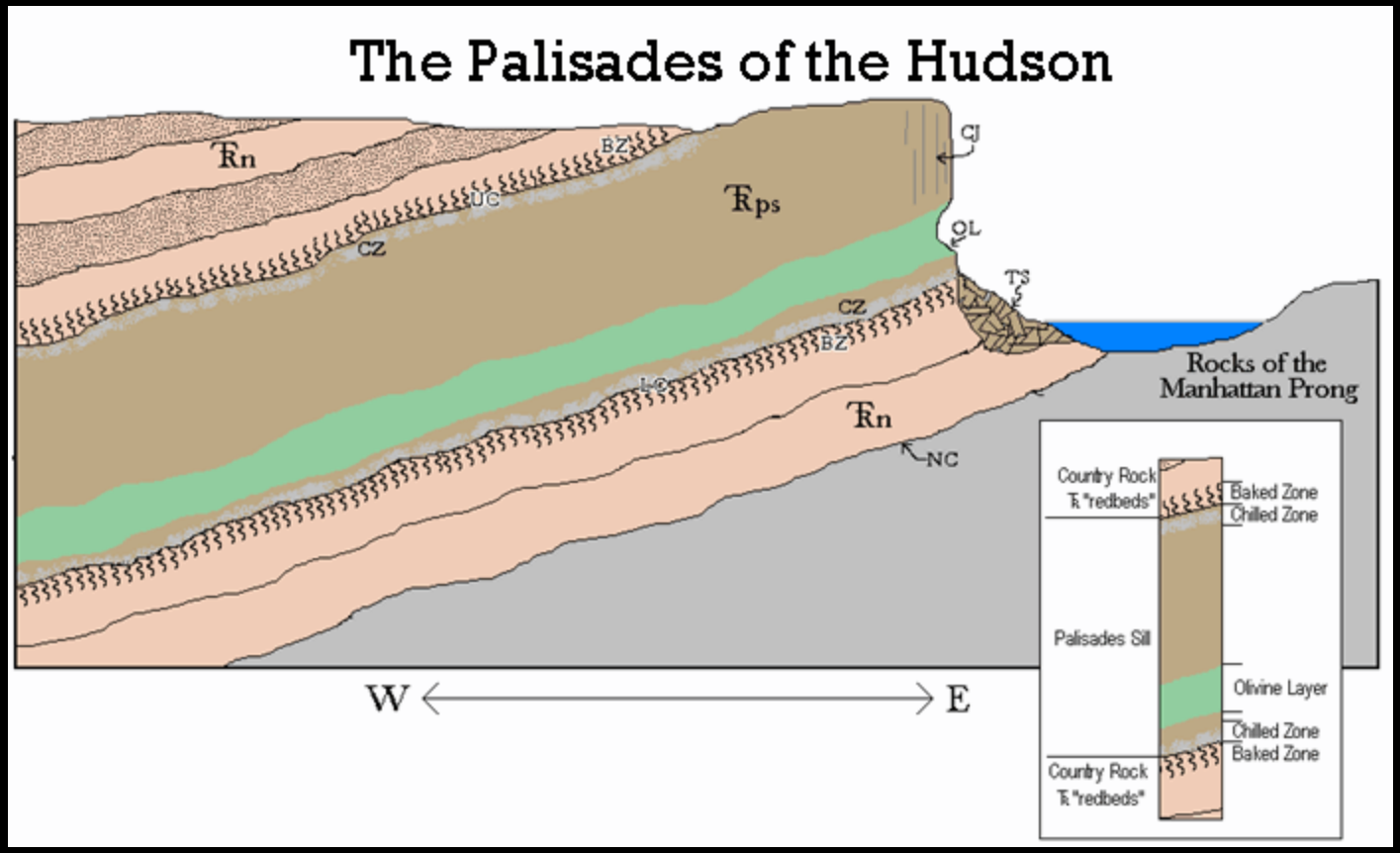
Newark Basin of New Jersey



http://3dparks.wr.usgs.gov/nyc/mesozoic/newarkbasin.htm

Sill

Concordant
Palisades Sill of New Jersey



Sill

Concordant
Palisades Sill of New Jersey

http:□□www.kurun.de□Articles□2004□Mai200

Sill

Concordant

Palisades Sill of New Jersey

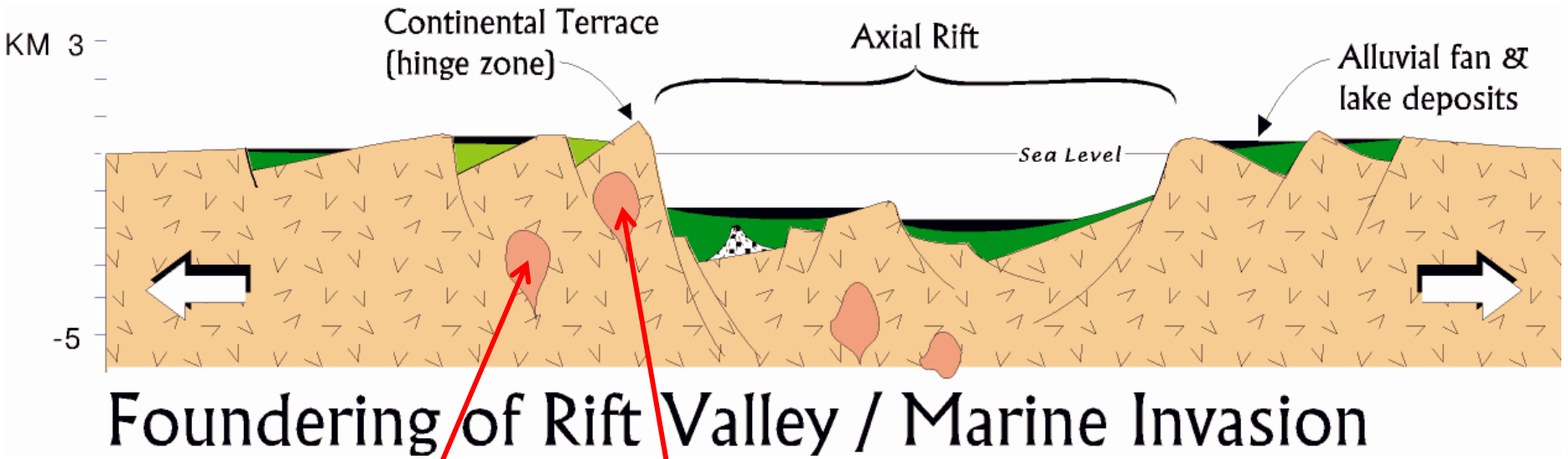
http://www.geography.hunter.cuny.edu/~cwang/geo-NYC/Summer2003trip-photos.htm

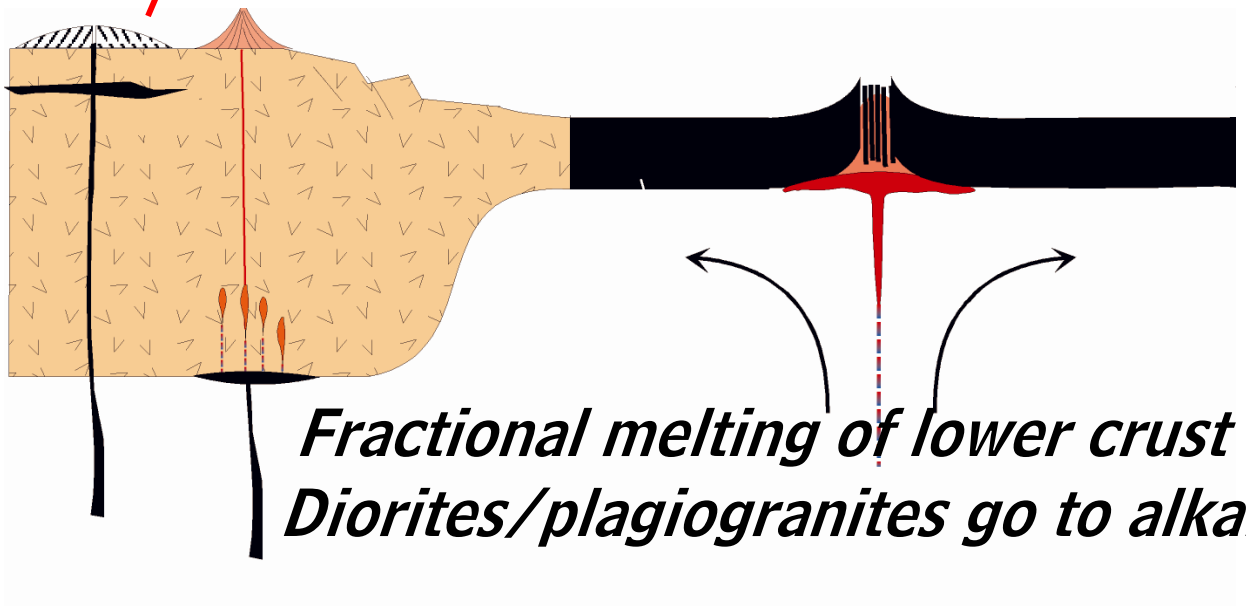
Triassic Dinosaur Footprints from Eastern North America

The mountains to the east of the site 200 million years ago.

http://www.casdn.neu.edu/~geology/department/staff/colgan/dinos/dino.htm

The Rifting Model





Fractional melting of lower crust
Diorites/plagiogranites go to alkali granites

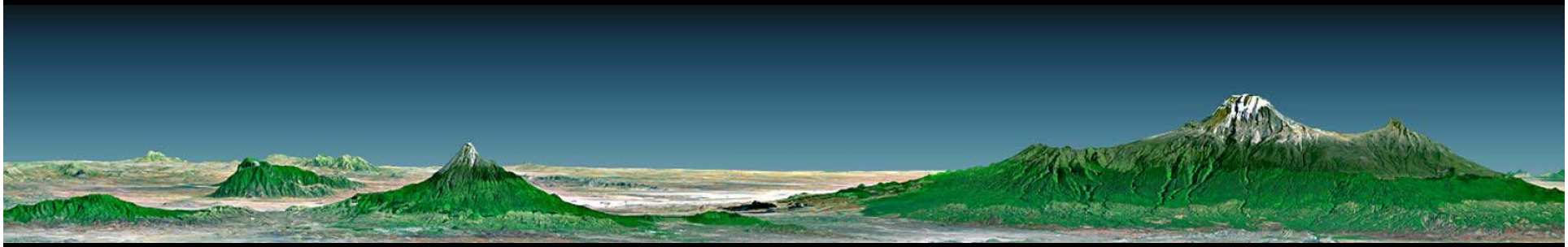
Alkali Granite

When a granitoid is devoid or nearly devoid of plagioclase the rock is referred to as alkali granite.

Alkali Granite

Mt. Kilimanjaro, East Africa

Mount Kilimanjaro

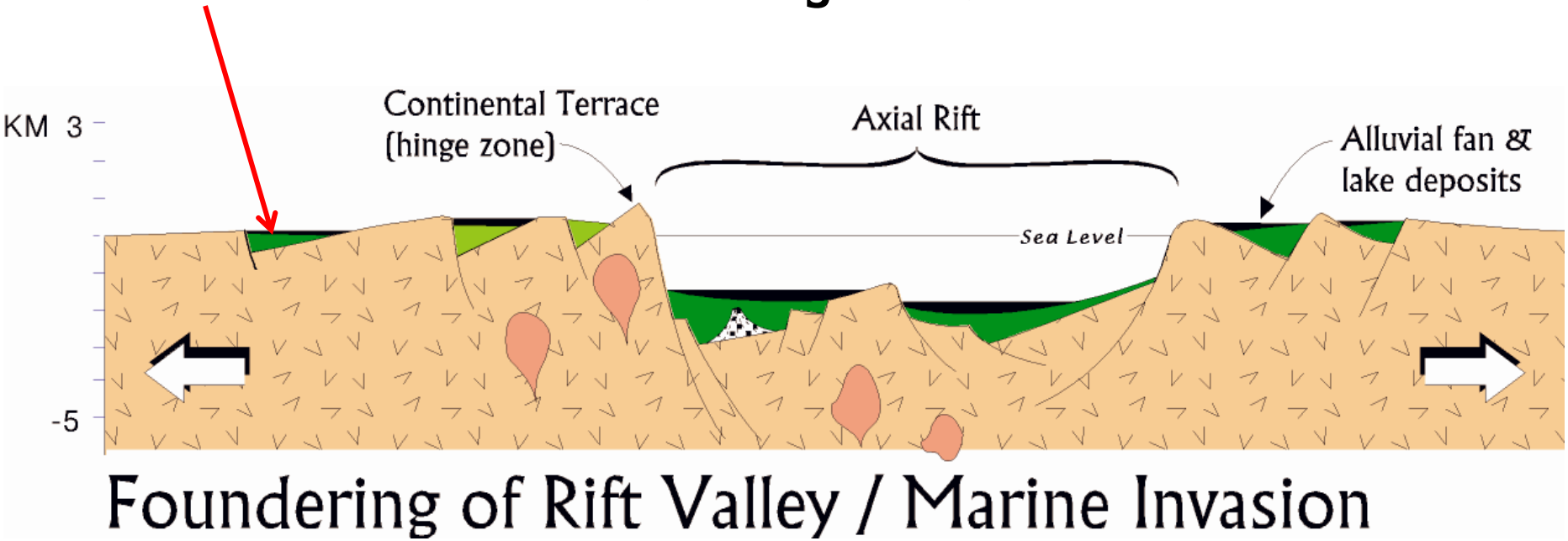


Mount Kilimanjaro (Kilima Njaro or "shining mountain" in Swahili), the highest point in Africa, reaches 5,895 meters (19,340 feet) above sea level, tall enough to maintain a permanent snow cap despite being just 330 kilometers (210 miles) south of the equator.

http://photojournal.jpl.nasa.gov/feature/Africa?sort=ASC&start=40&subselect=refine%3Ayes

Mt. Kilimanjaro, East Africa

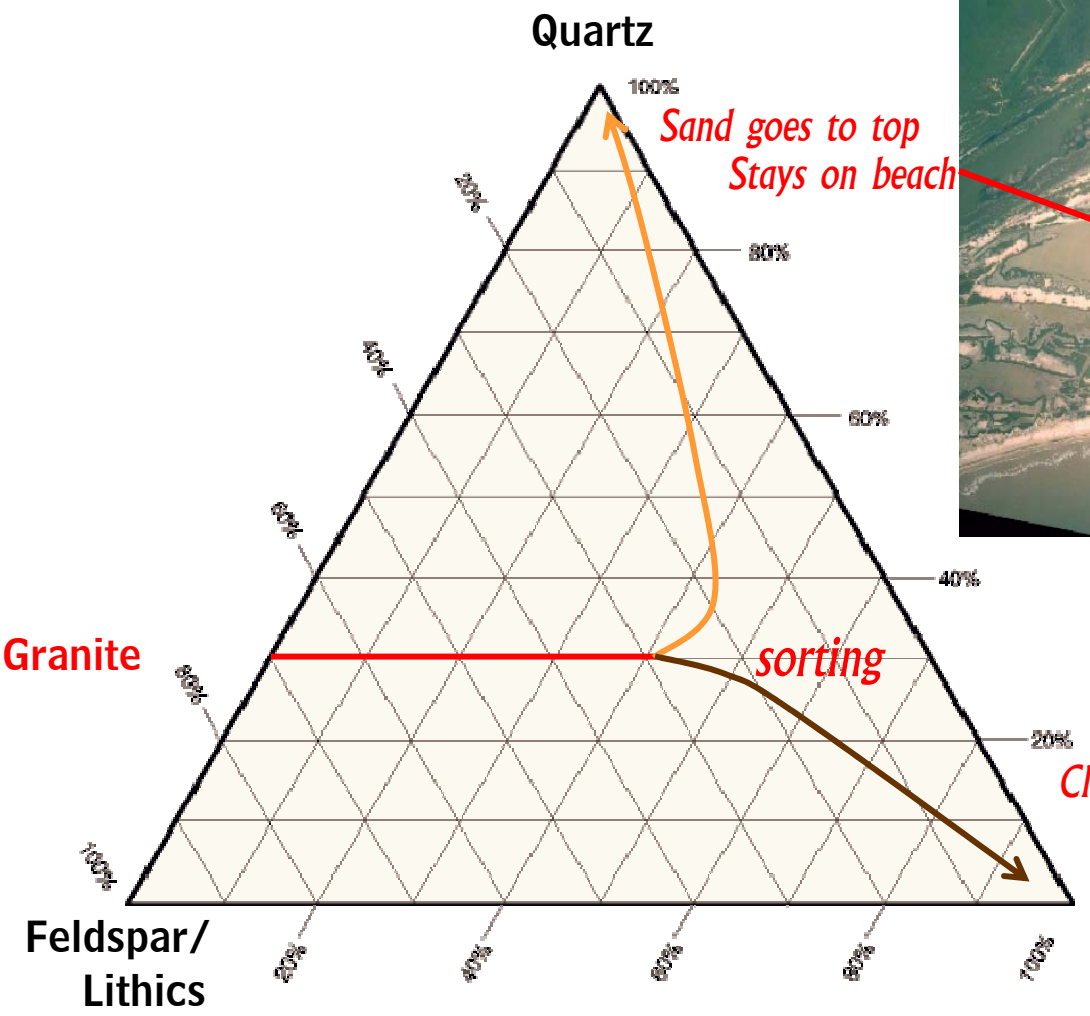
The Rifting Model



Sediment Evolution on a Ternary Diagram

4

Weathering and Sorting



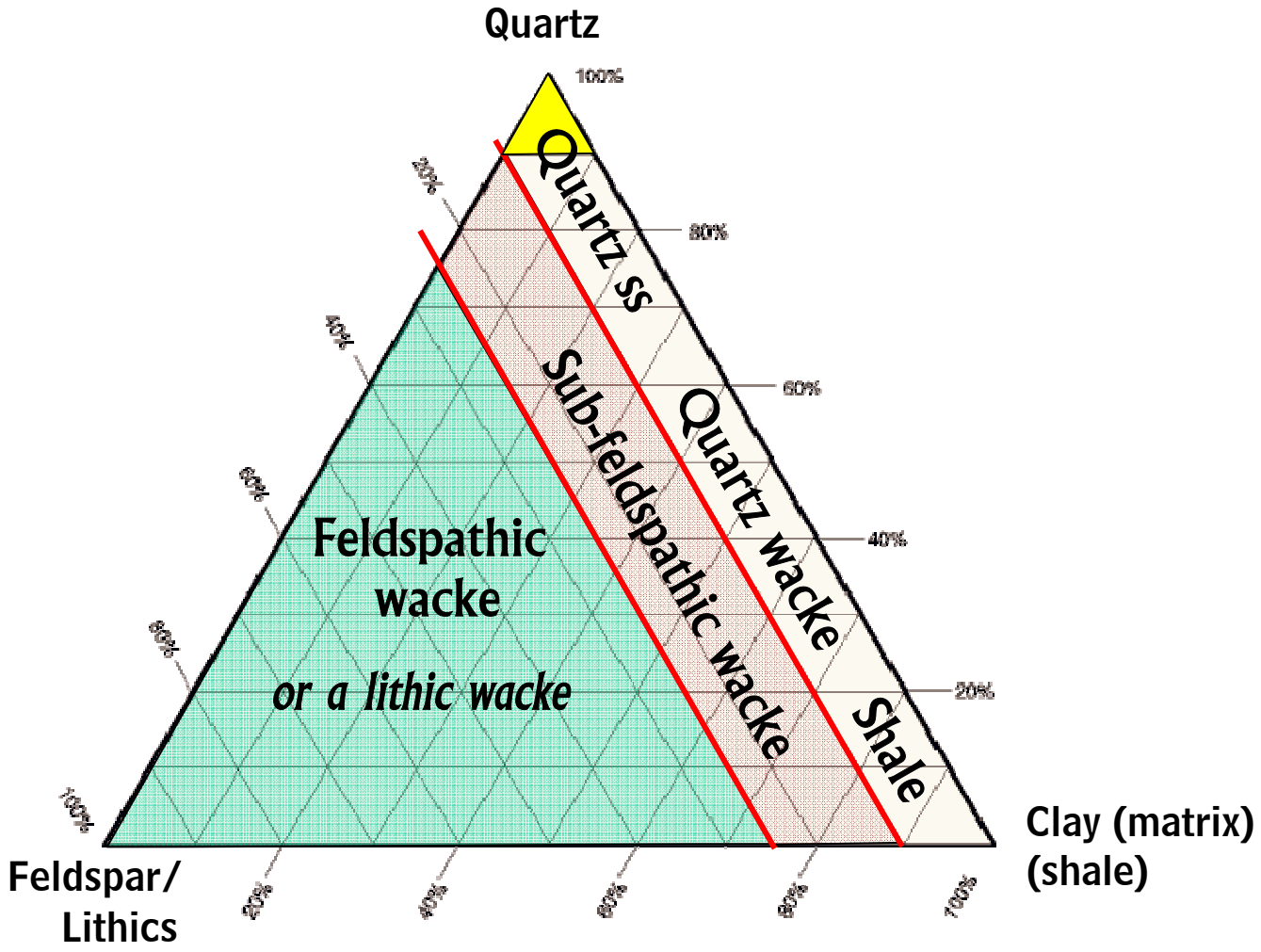
30% Q
70% F & L

Granite

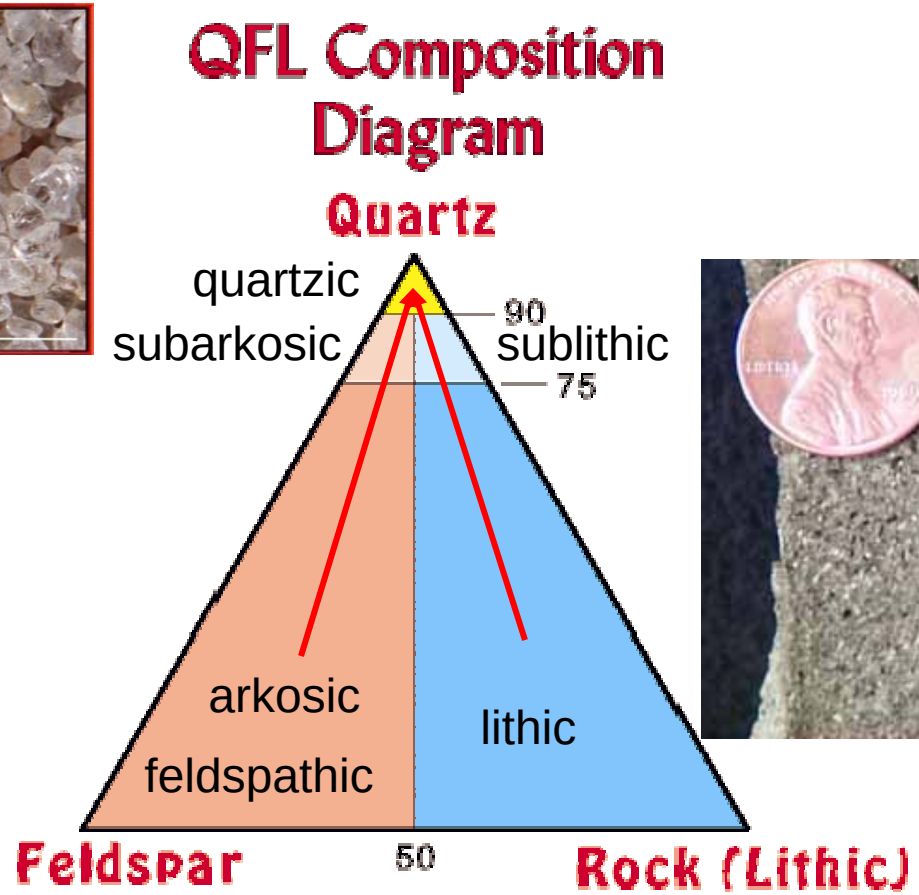
30% Q
70% clay

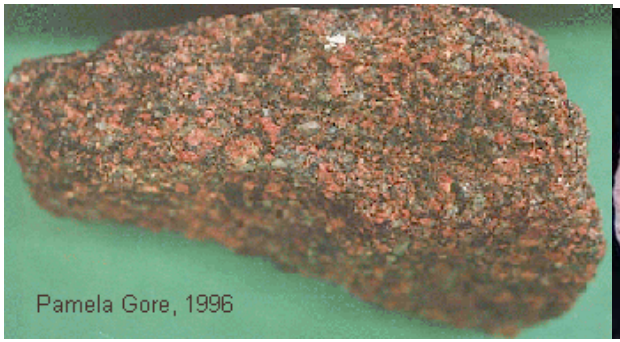
Sediment Evolution on a Ternary Diagram

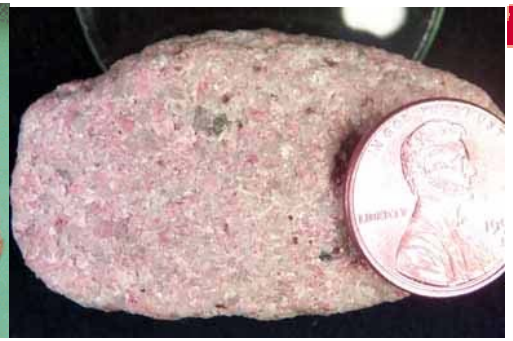
8



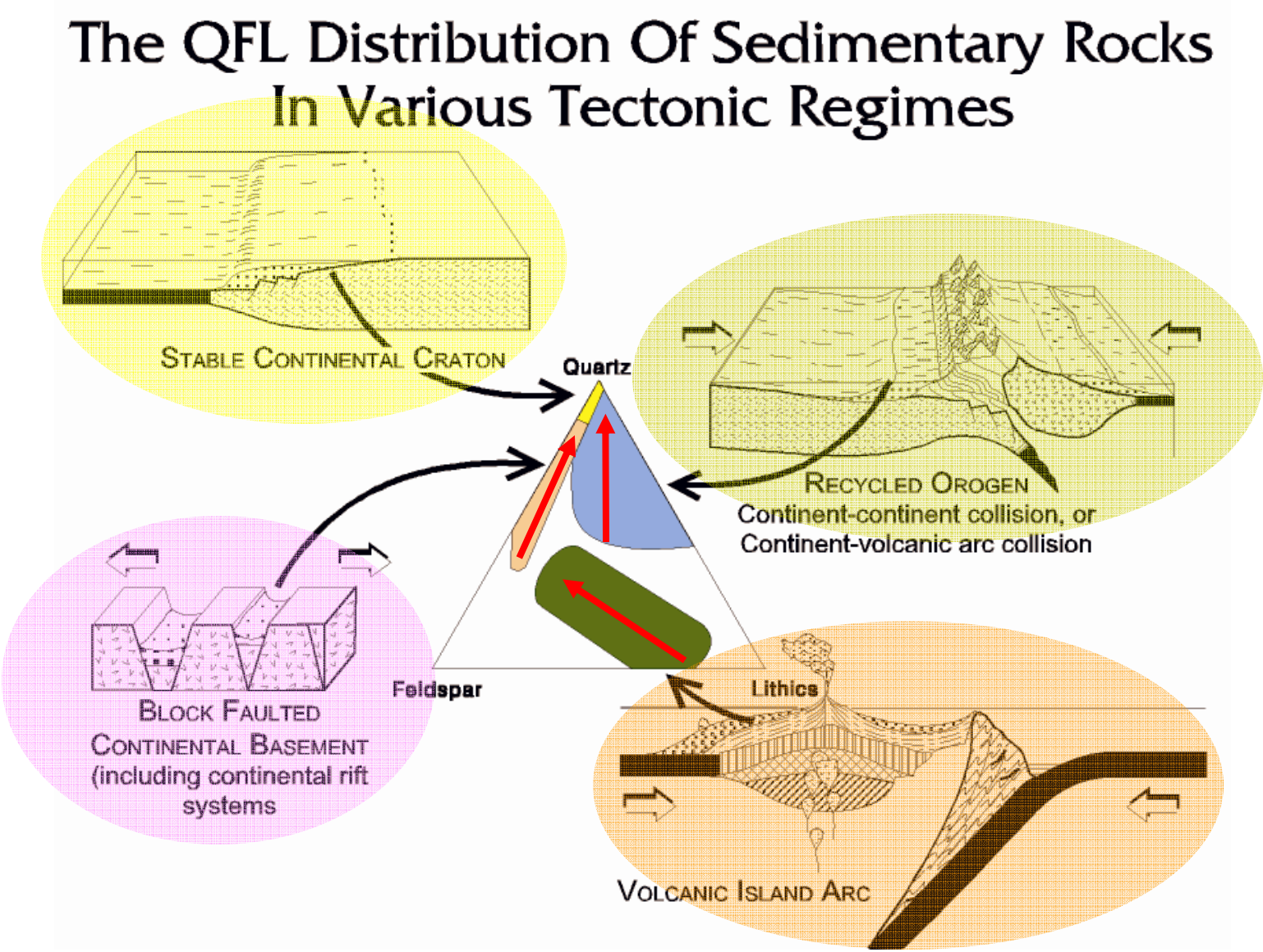
Ternary Classification of Clastic Sedimentary Rocks



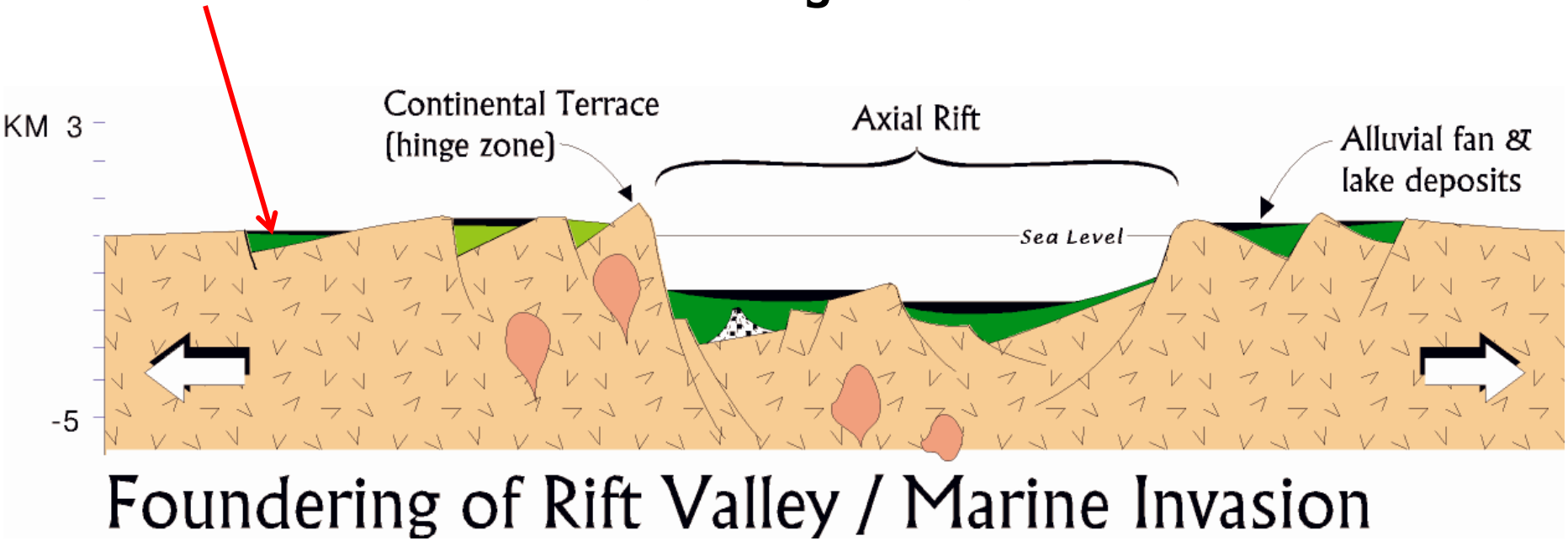




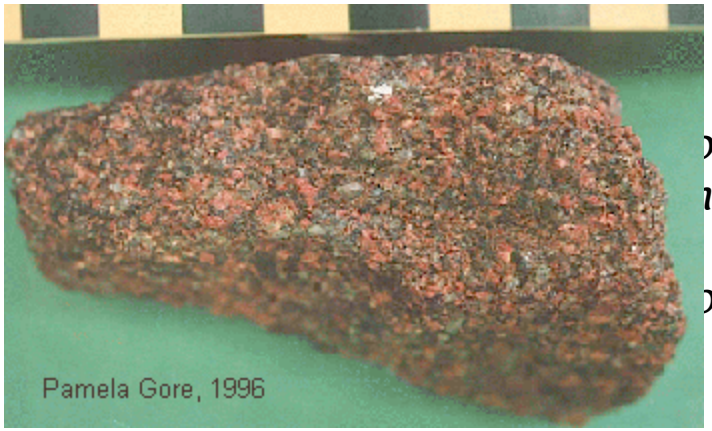
And, . . . Sedimentary Rocks Evolve . . .



The Rifting Model



Foundering of Rift Valley / Marine Invasion



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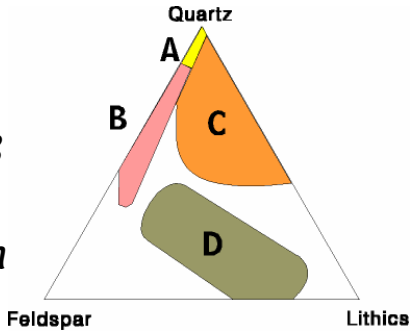
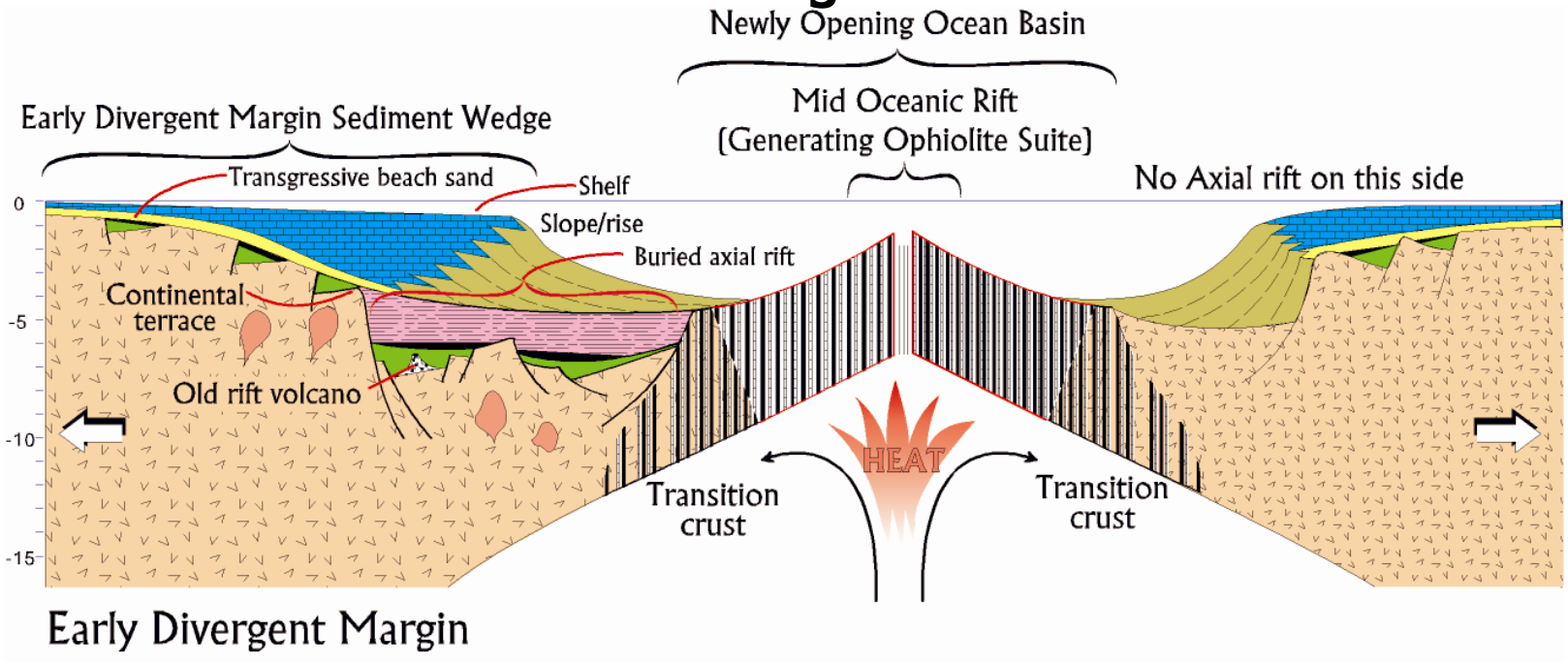
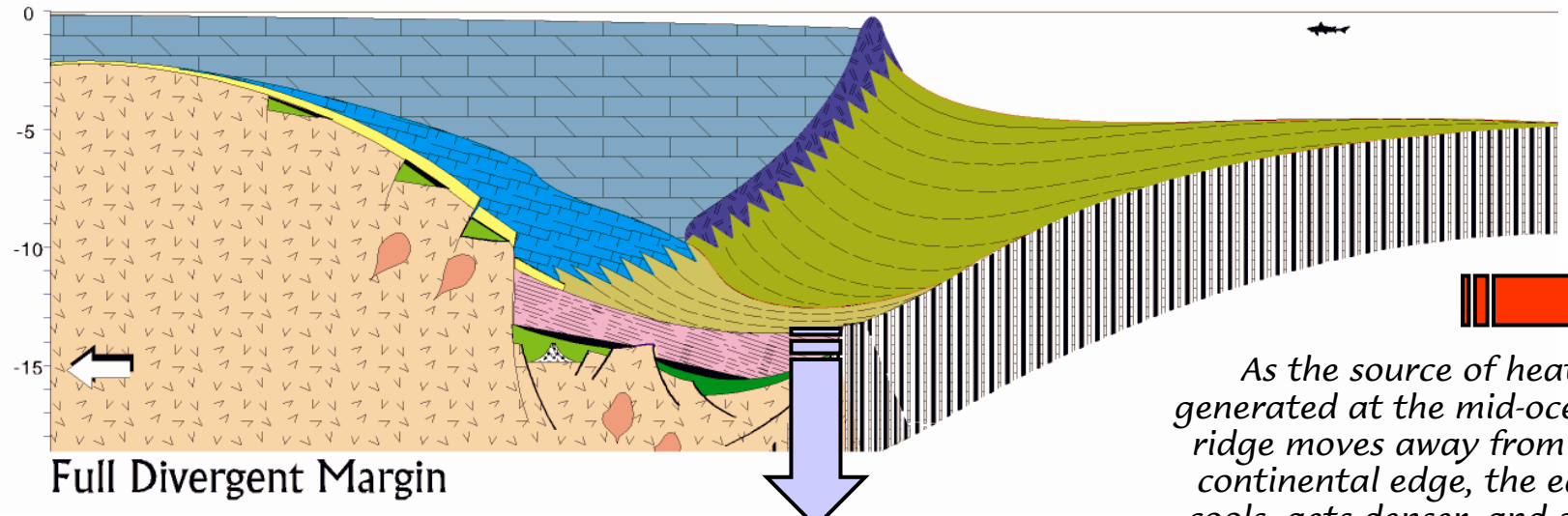


The Rifting Model



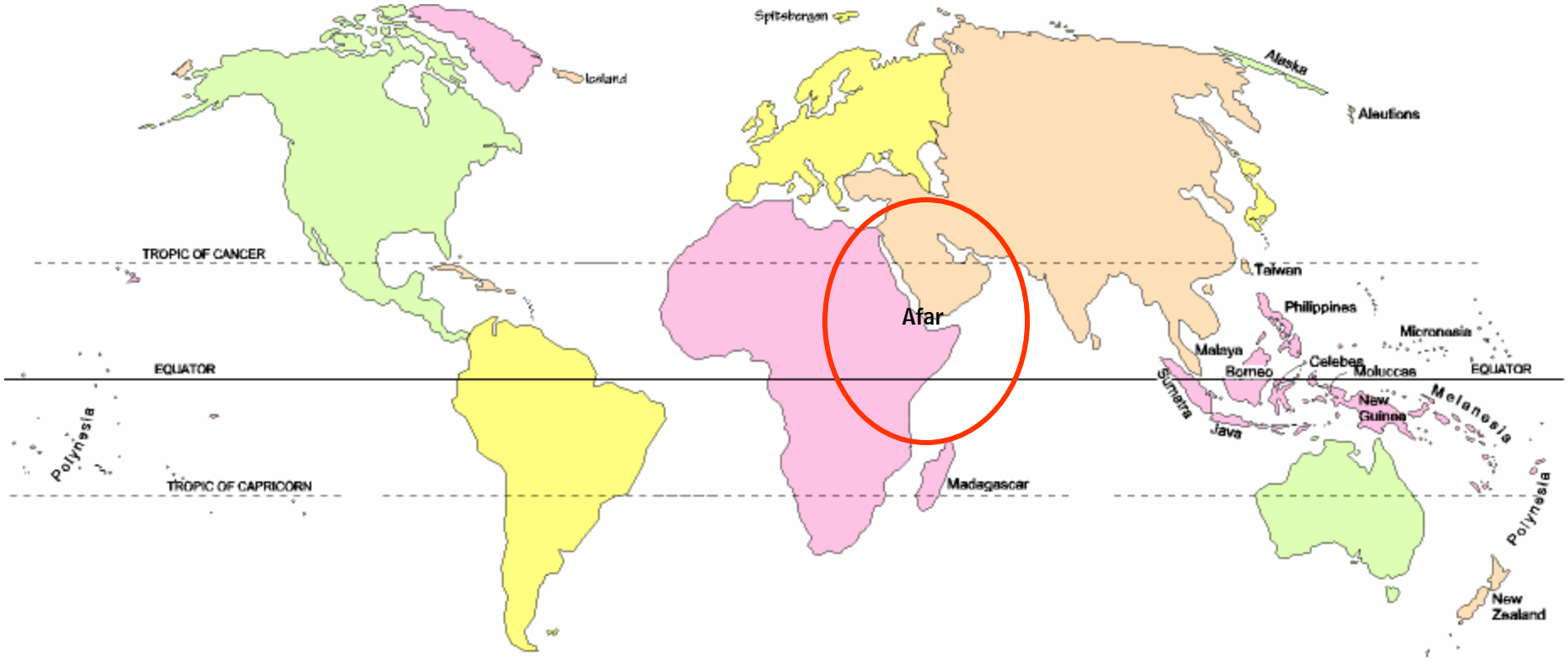


As the source of heat generated at the mid-oceanic ridge moves away from the continental edge, the edge cools, gets denser, and sinks

Cooling and sinking

The Rifting Model

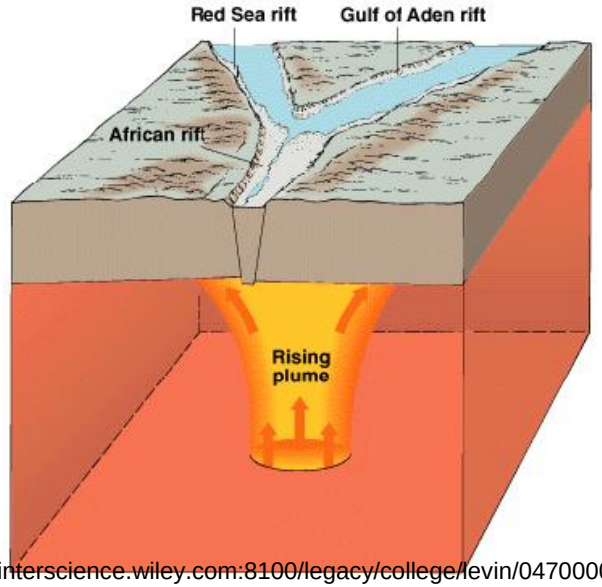
In the world today there is only one clear, obvious rifting event taking place on a continent, centered in the Afar triangle in north west Africa and Arabia.



The Red Sea

A hypersaline marine environment in a desert that is part of a triple junction

http://enchanted-castle.ath.cx/our_image_gallery.htm

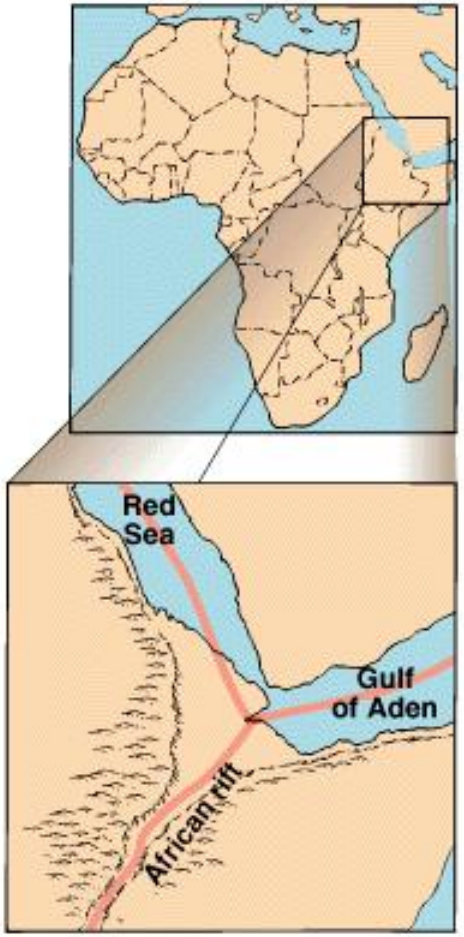


http://www3.interscience.wiley.com:8100/legacy/college/levin/0470000201/chap_tutorial/ch07/chapter07-1.html

http://forums.photobucket.com/showthread.php?t=1290&page=2

The Rifting Model

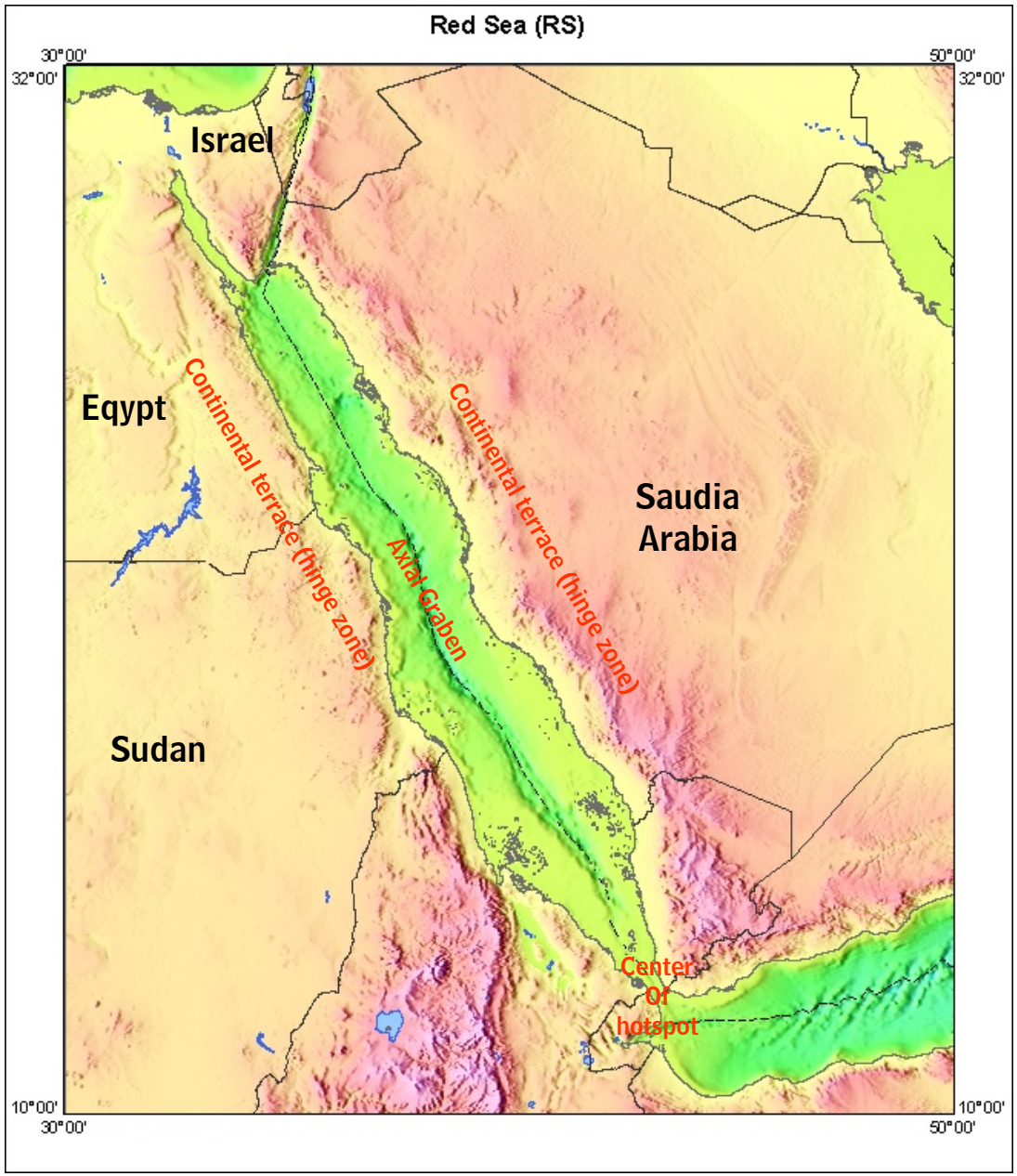
The Modern Triple Junction in northeast Africa



http://www3.interscience.wiley.com:8100/legacy/college/levin/0470000201/chap_tutorial/ch07/chapter07-1.html

http://www.informatuttonet.com/atlante/homepage.htm

The Rifting Model



http://walrus.wr.usgs.gov/infobank/gazette/html/regions/rs.htm

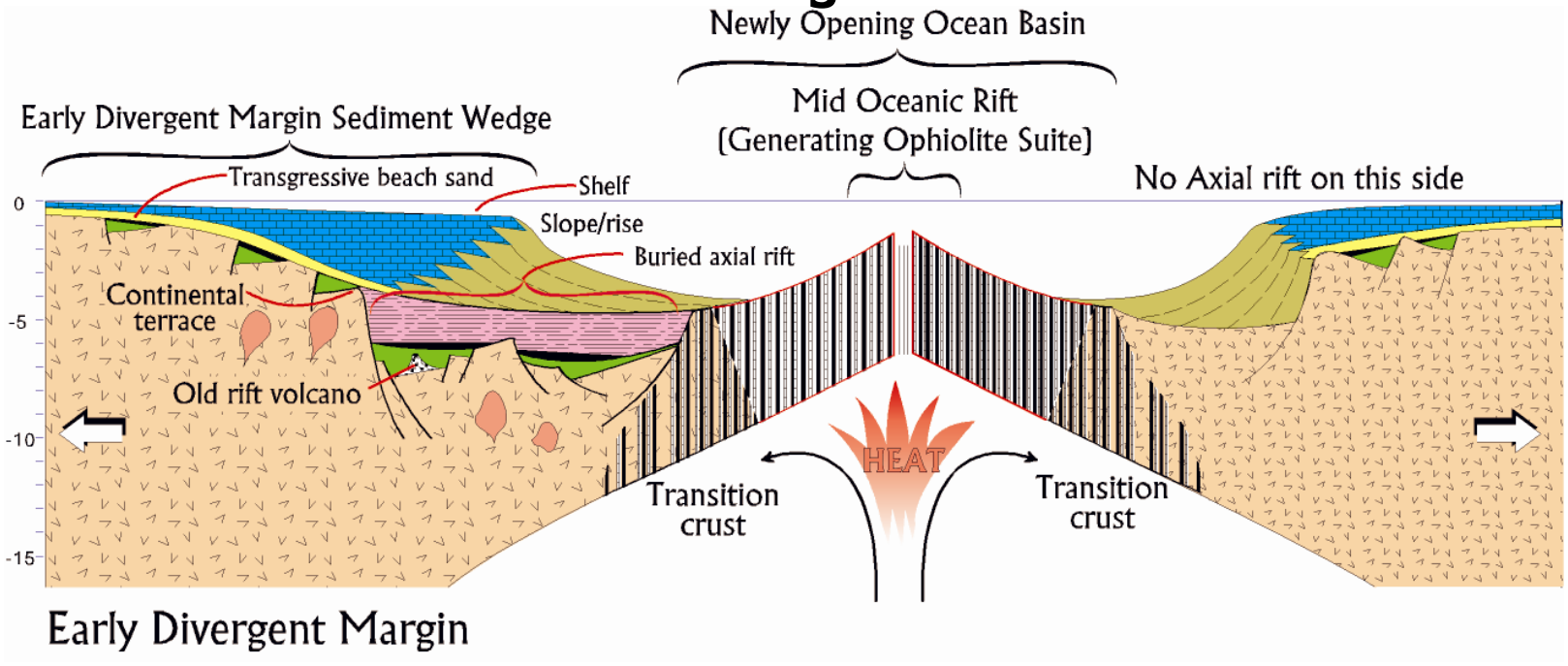
The Rifting Model

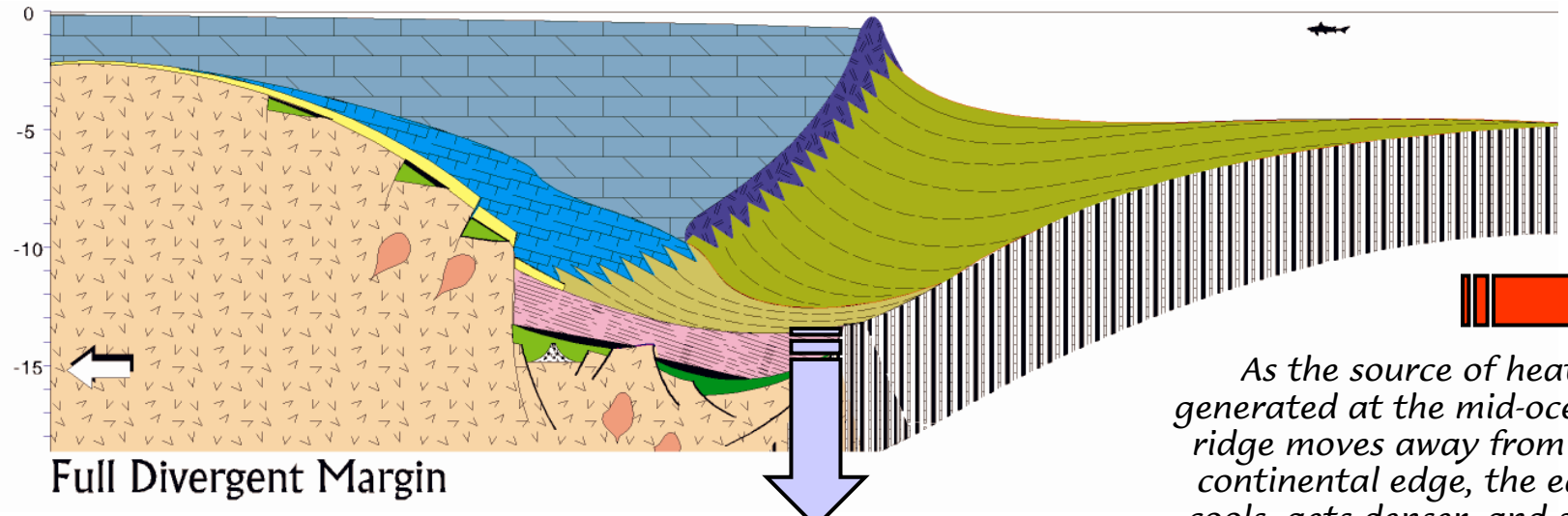
The Modern Triple Junction in northeast Africa

At the northern end of the Red Sea we see the tear of the rifting propagating northward and splitting into two arms as it goes. The small lake on the upper right is the Dead Sea; notice how it is sitting in a graben. In a few million years the tear will be complete and the Red Sea and the Mediterranean Sea will be joined. No more need for the Suez canal.

http://www.utexas.edu/depts/grg/hudson/grg301c/hudson_grg_301c/schedule/3_rocks_earth_images/6_tectonics/11.htm

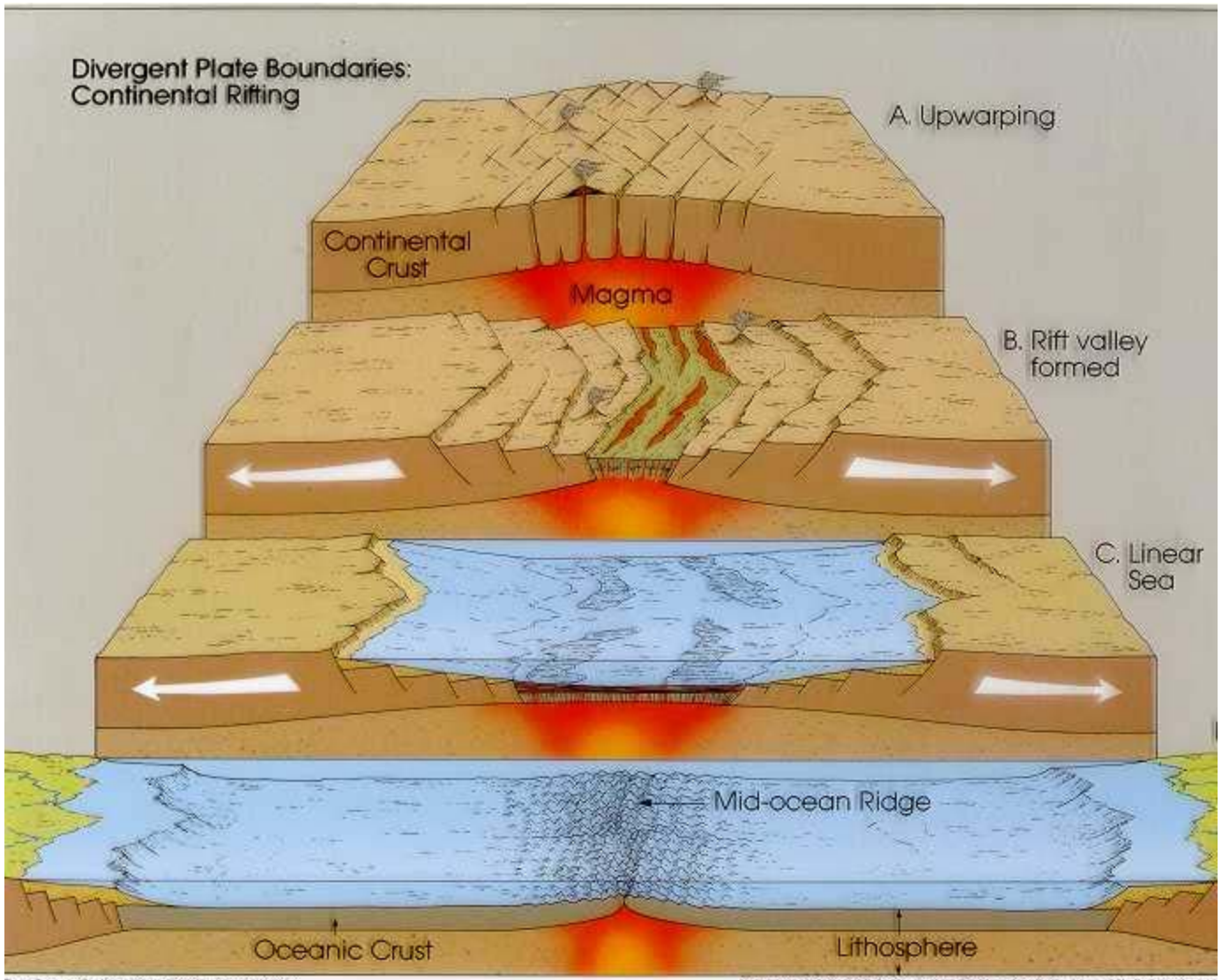
The Rifting Model





As the source of heat generated at the mid-oceanic ridge moves away from the continental edge, the edge cools, gets denser, and sinks

Cooling and sinking


Divergent Plate Boundaries:
Continental Rifting
A. Upwarping
Continental Crust
Magma
B. Rift valley formed
C. Linear Sea
Mid-ocean Ridge
Oceanic Crust
Lithosphere
The Tasa Collection: Plate Tectonics
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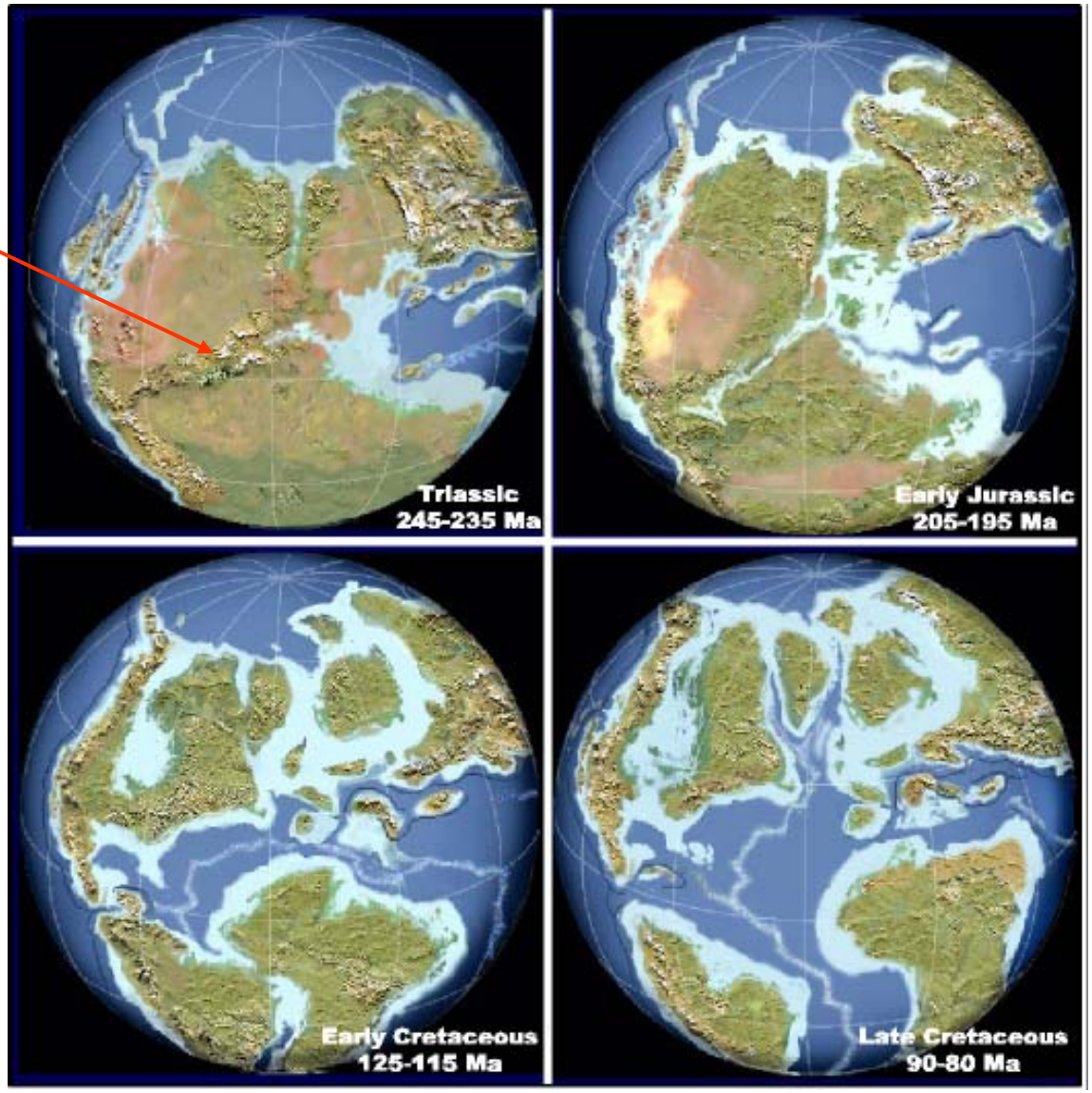
The Rifting Model

Maps Showing the Rifting of the Pangae Supercontinent And Opening of the Atlantic Ocean about 250 Million Years Ago

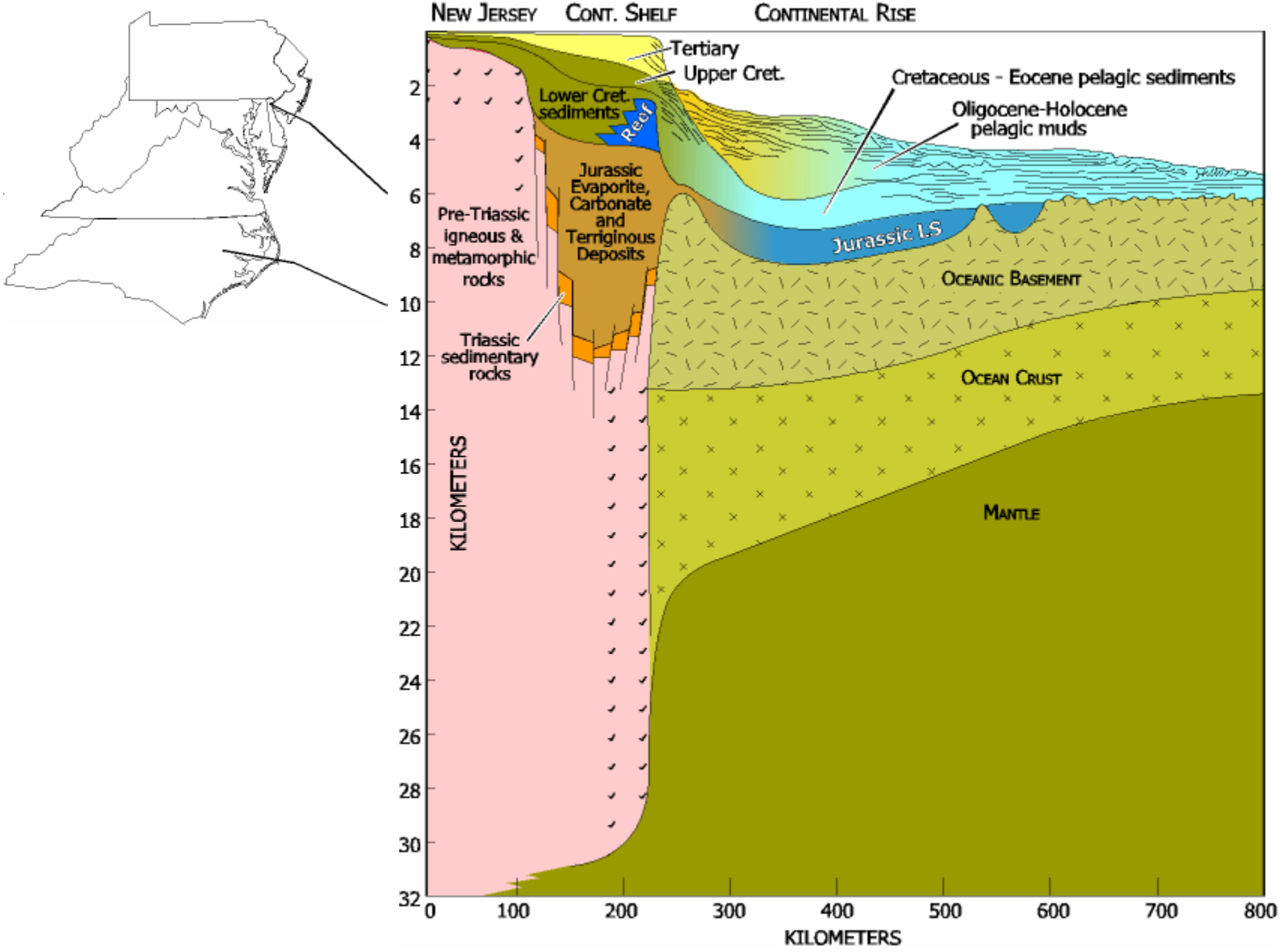
Approximate location of Virginia



http://vishnu.glg.nau.edu/rcb/global_history.html.

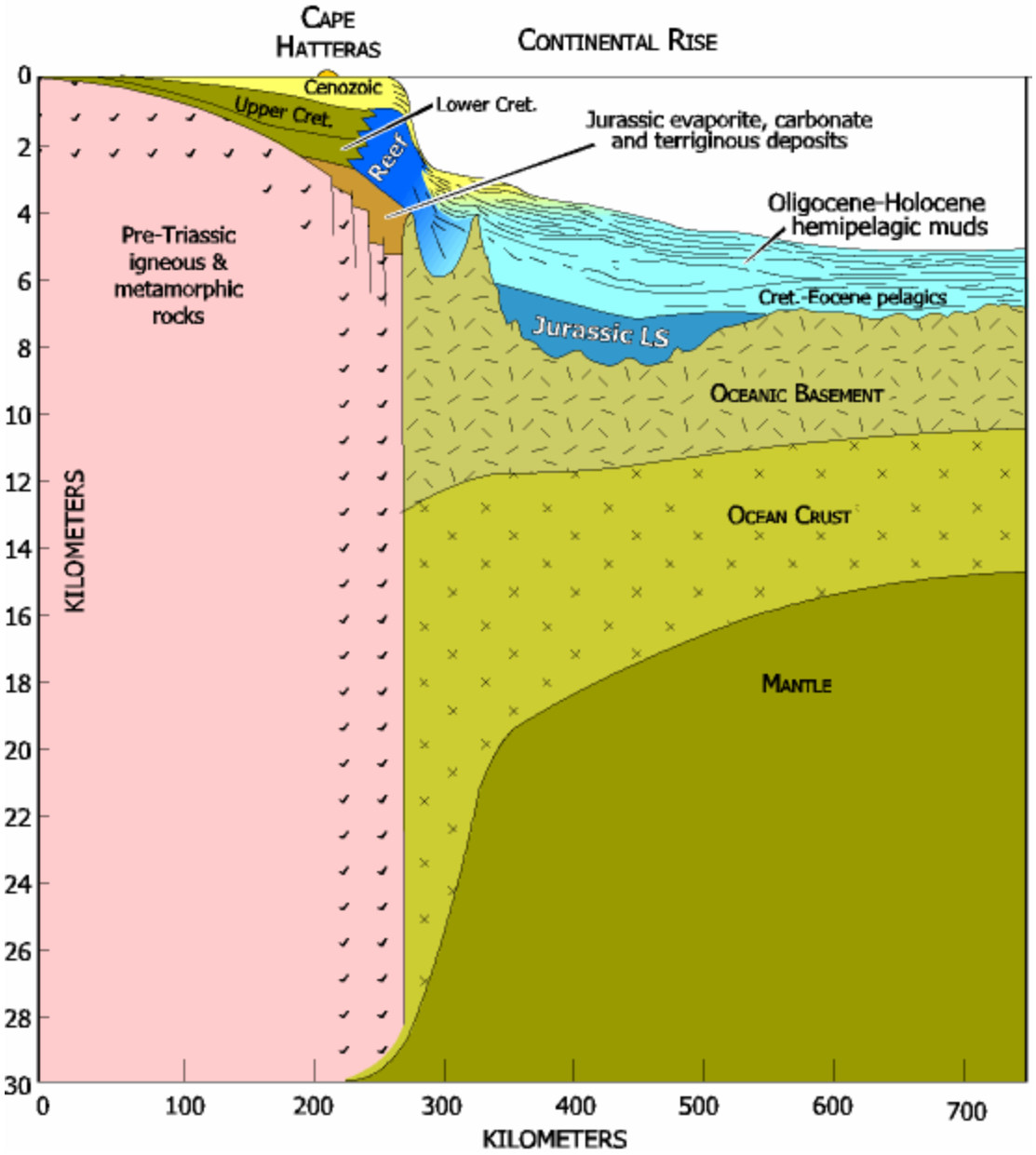
The Rifting Model

A Modern Divergent Continental Margin



The Rifting Model

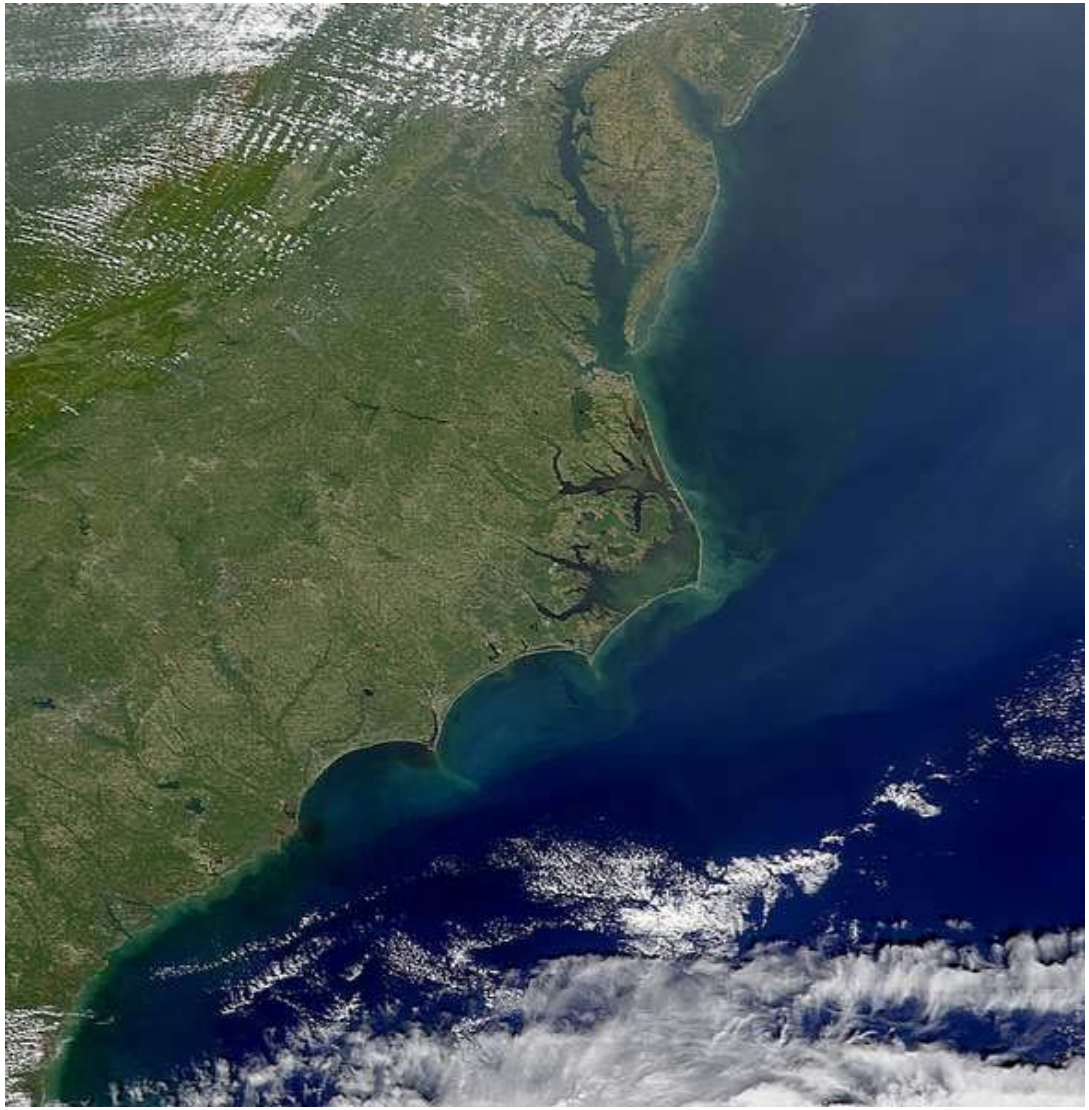
A Modern Divergent Continental Margin



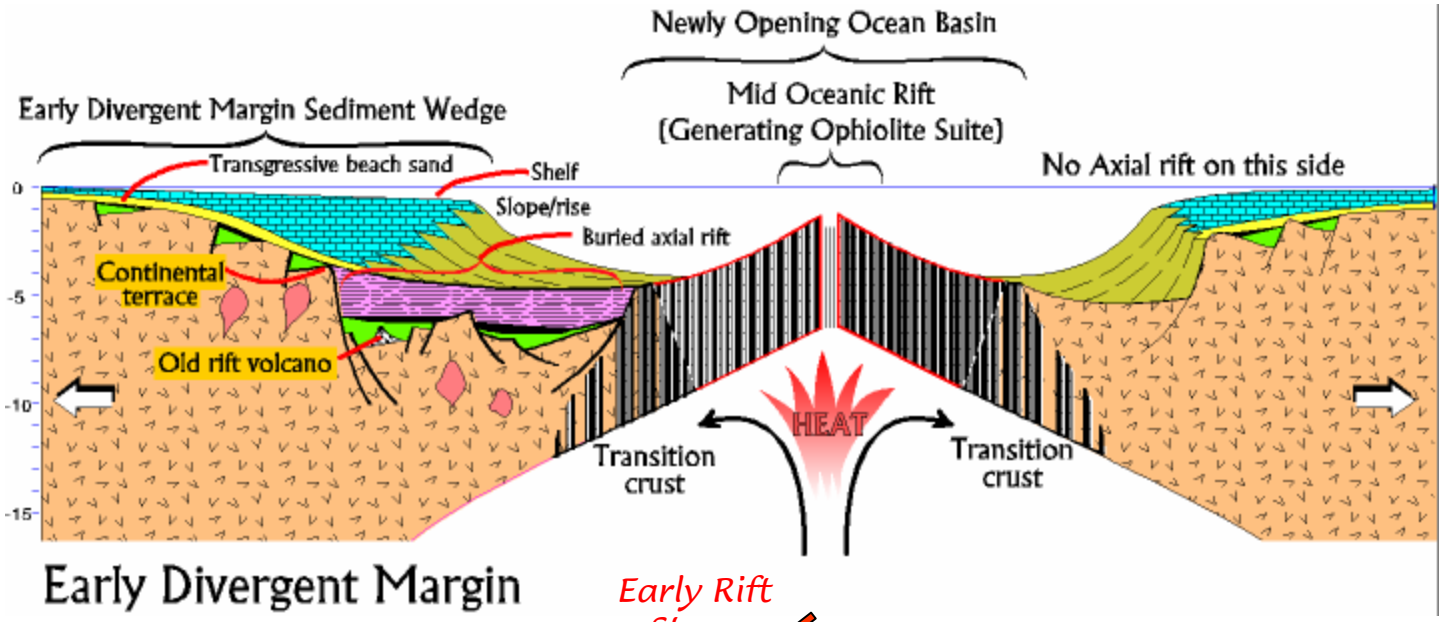
The Rifting Model

A Modern Divergent Continental Margin

All the great complex of geologic processes that compose the Atlantic coast today and that we are so familiar with are just the most recent events in a history that began over 200 million years ago.



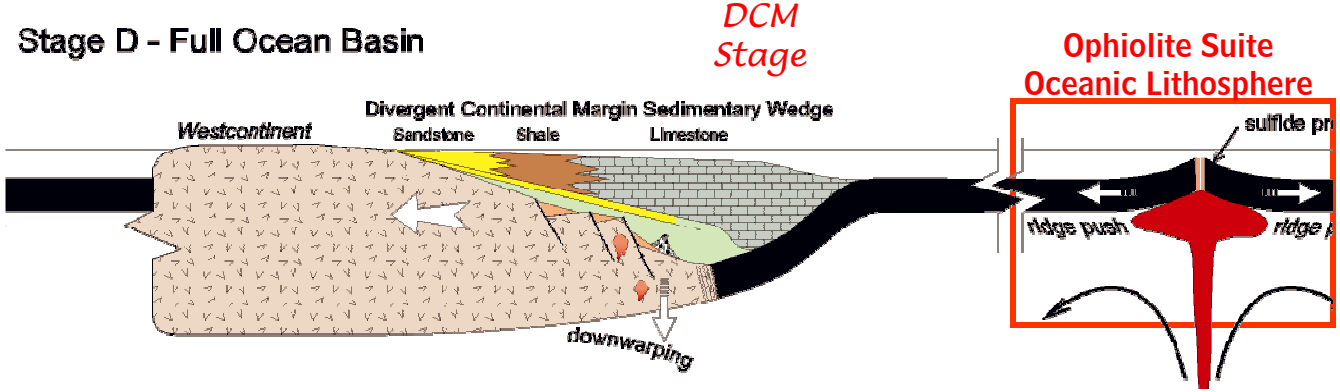
The Creation of Oceanic Lithosphere
The Ophiolite Suite



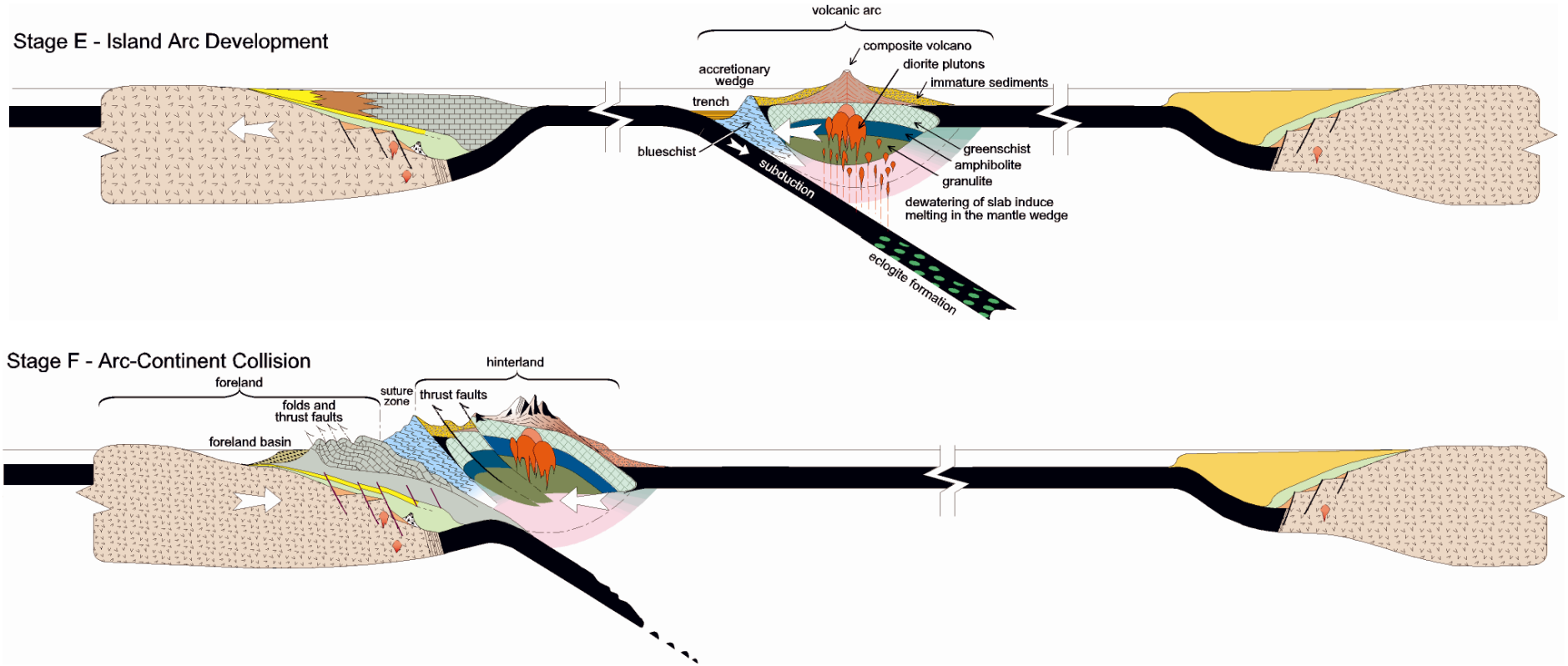
Early Rift Stage

Evolves into

DCM Stage



Wilson Cycle
First Closing Phase



Island Arc Orogeny (Stage E)
Followed by an
Arc-Continent Collision Orogeny (Stage F)

Wilson Cycle
Second Closing Phase

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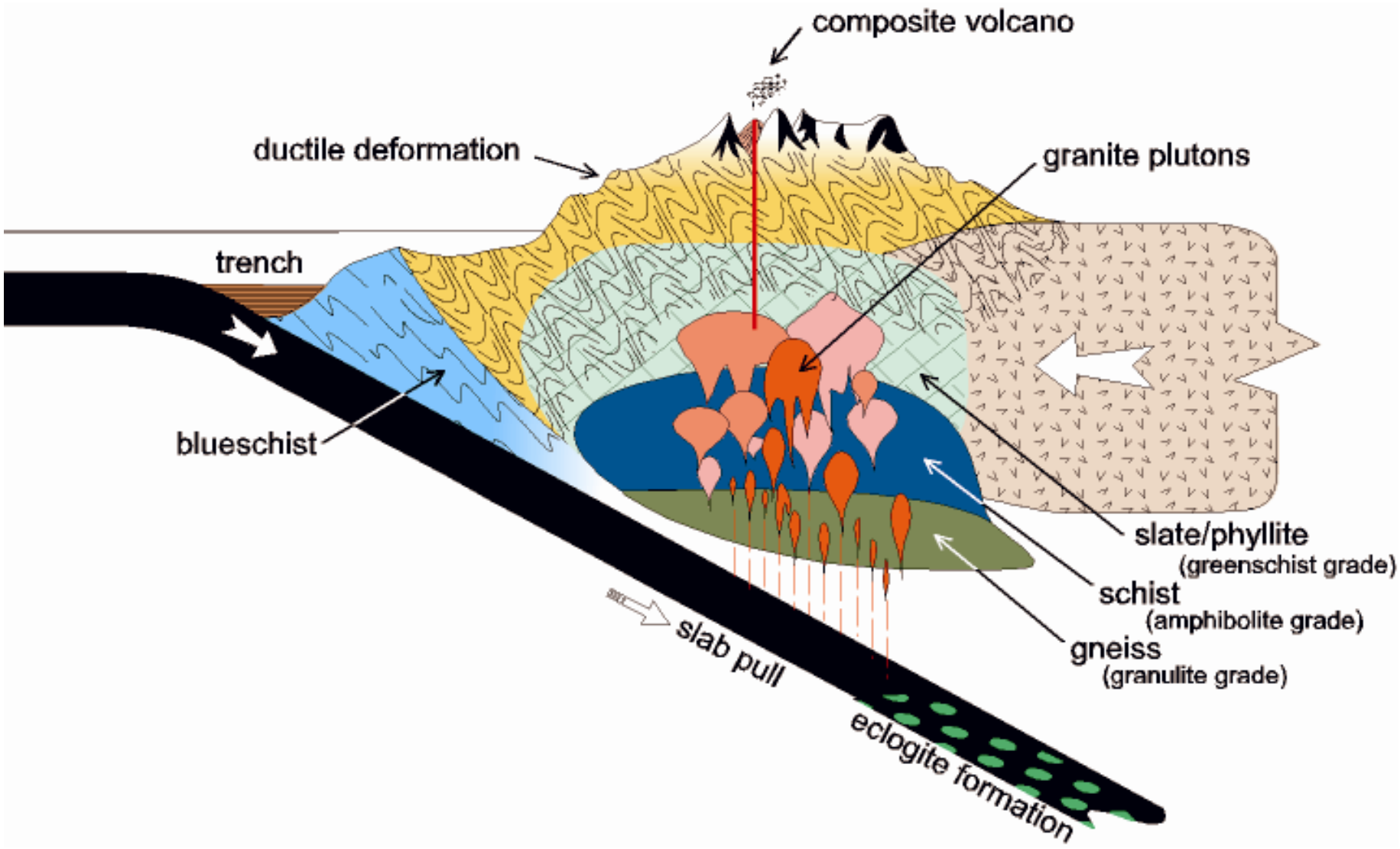
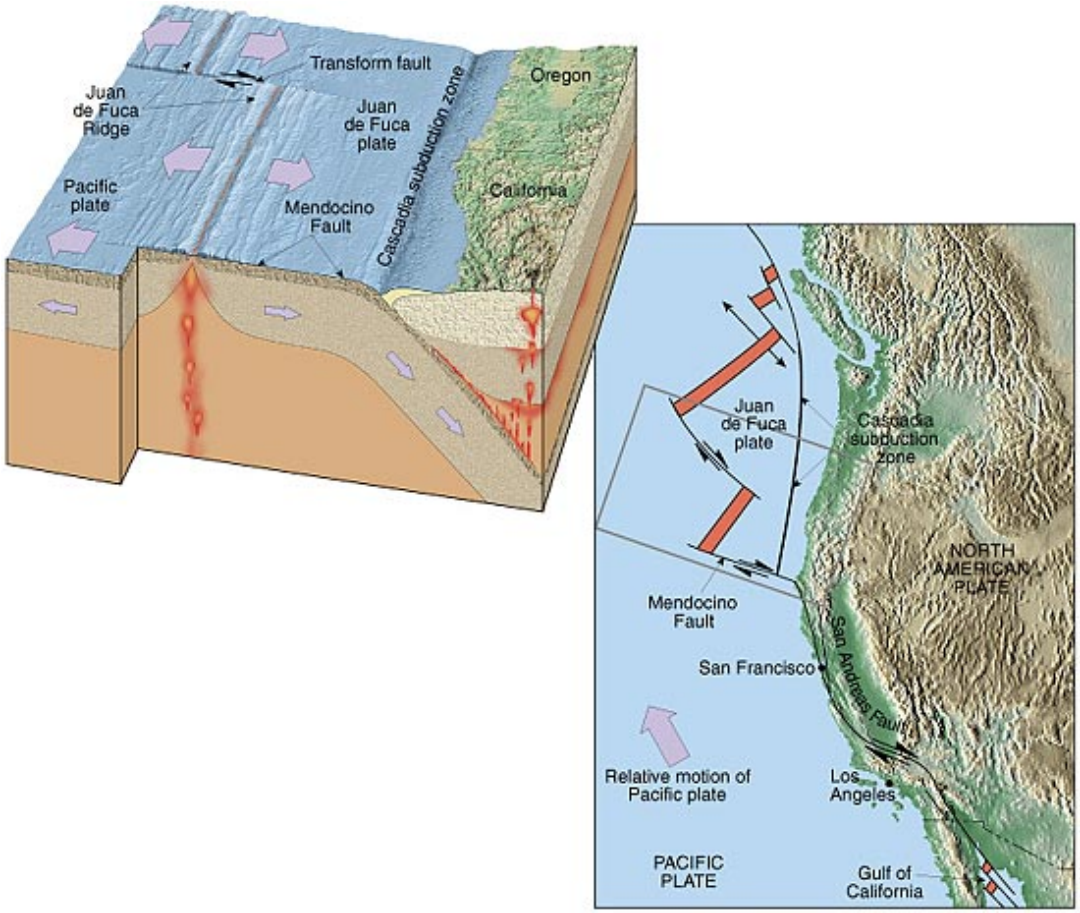


Cordilleran Orogeny: Cascade Mountains



http://dn.redwoods.edu/coursenotes/renner/spring04/geol10/online_lectures/ch03.html

Cordilleran Orogeny: Cascade Mountains

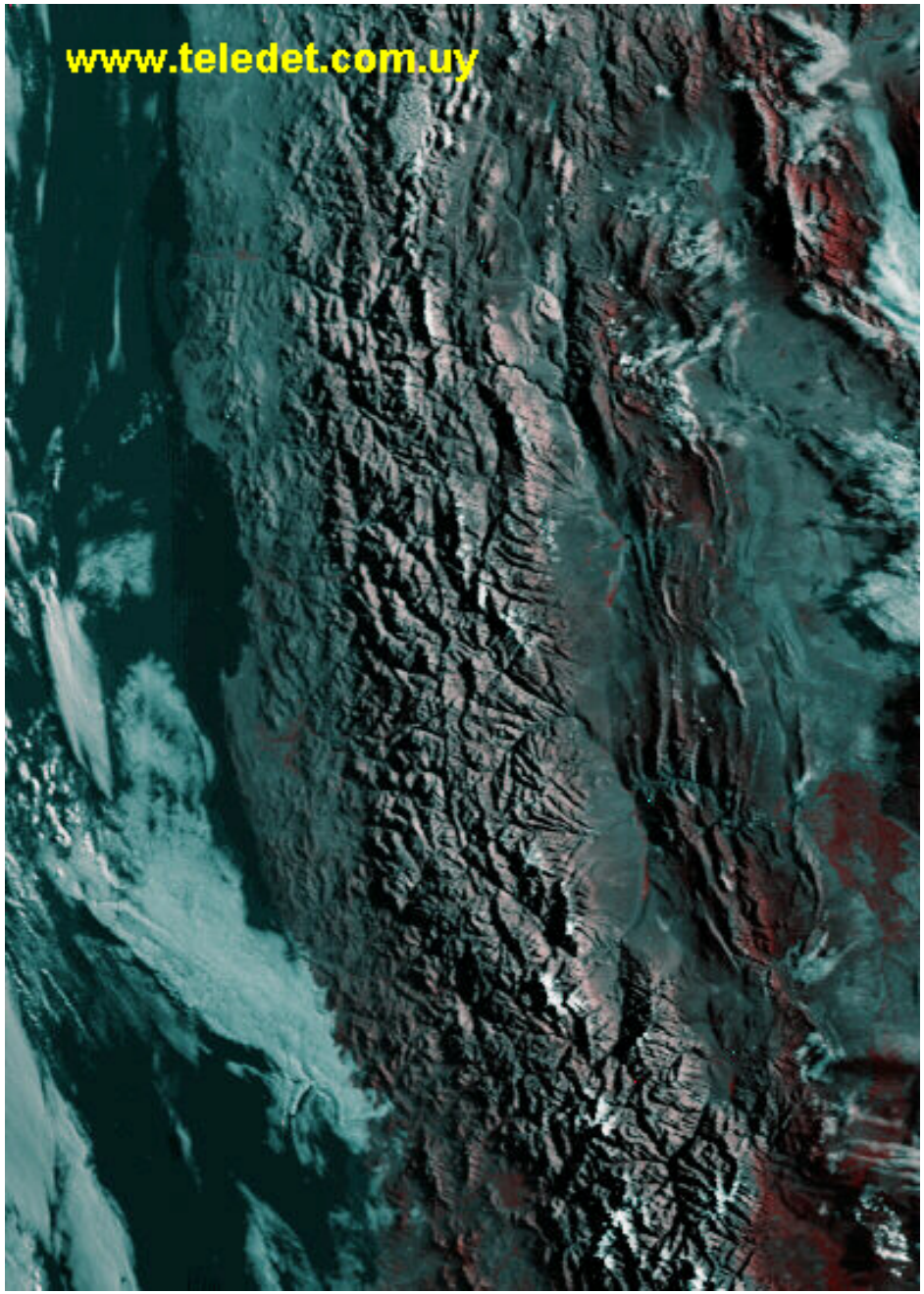
Composite Volcano – Cascade Mountains – Mt. St. Helens

http://www.utexas.edu/depts/grg/hudson/grg301c/hudson_grg_301c/schedule/3_rocks_earth_images/7_quakes_volcanism/6.jpg

Cordilleran Orogeny: Andes Mountains

http://www.cliffshade.com/colorado/tectonics.htm

Cordilleran Orogeny: Andes Mountains



http://www.teledet.com.uy/imagenes.htm

Cordilleran Orogeny: Andes Mountains

http://www.astro.uni-bonn.de/~maltmann/photgal_cz.html

Cordilleran Orogeny: Andes Mountains

http://www.astro.uni-bonn.de/~maltmann/photgal_cz.html

Cordilleran Orogeny: Andes Mountains

http://web.mit.edu/belloni/www/Personal.html

Cordilleran Orogeny: Andes Mountains

The magnificient volcano Osorno and Lago Llanquihue

Batholiths

Discordant

El Capitan - part of the Sierra Nevada Batholith

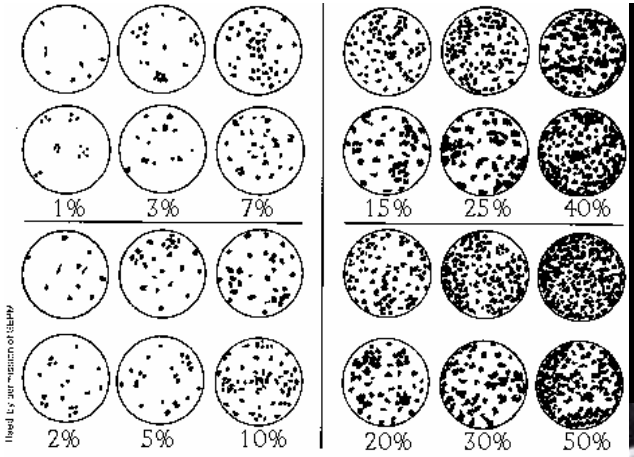
http://www.calstatela.edu/faculty/acolvil/igneous.html

Batholiths

Discordant

View from the top of Half Dome - more of the Sierra Nevada Batholith

http://newterra.chemeketa.edu/Faculty/fraa/geology/topics/IGNEOUS/photos/htmls/%7Fbatholith.html


1%
3%
7%
15%
25%
40%
2%
5%
10%
20%
30%
50%

Diorite:

0 – 5% quartz,
Na plagioclase and amphibole in about equal amounts

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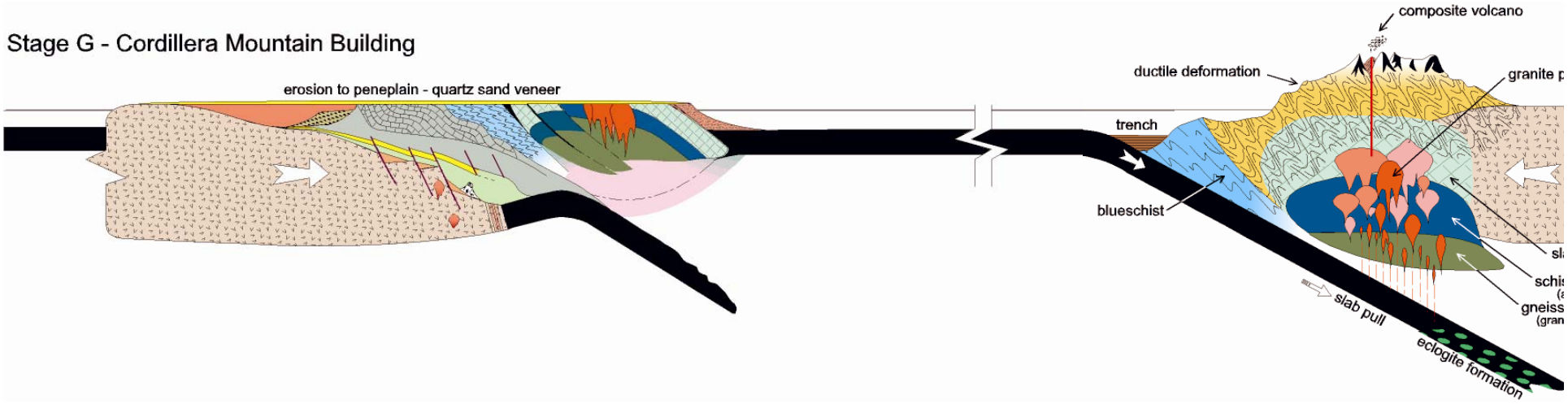
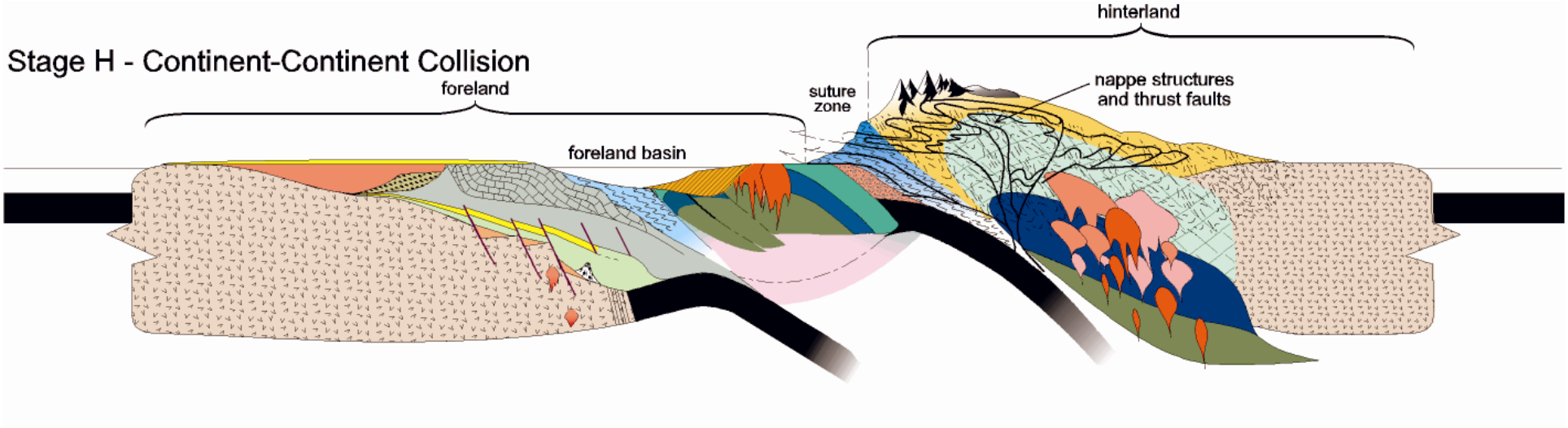
Wilson Cycle
Third Closing Phase



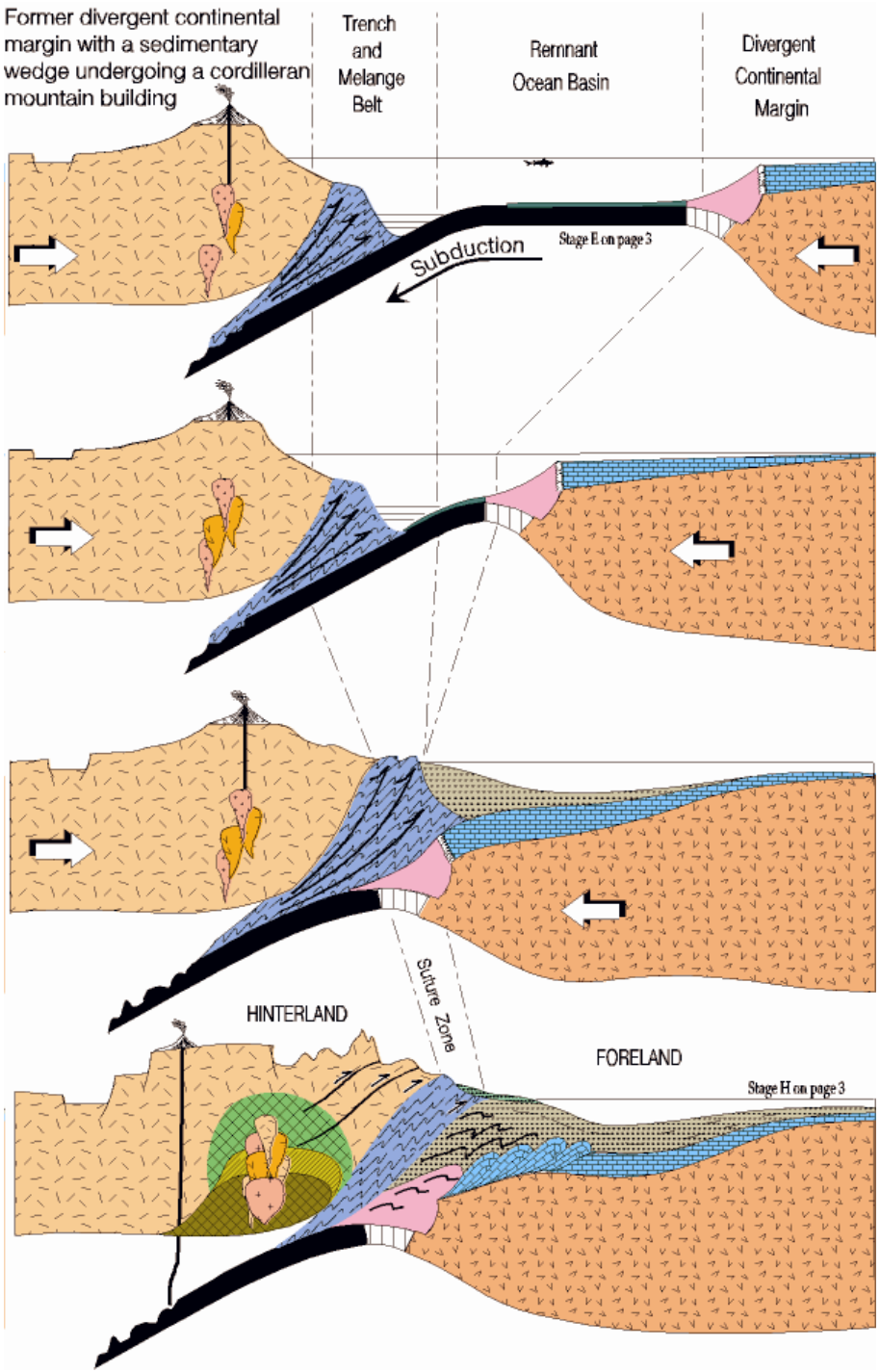
Continent-Continent Collision Orogeny

Wilson Cycle
Third Closing Phase

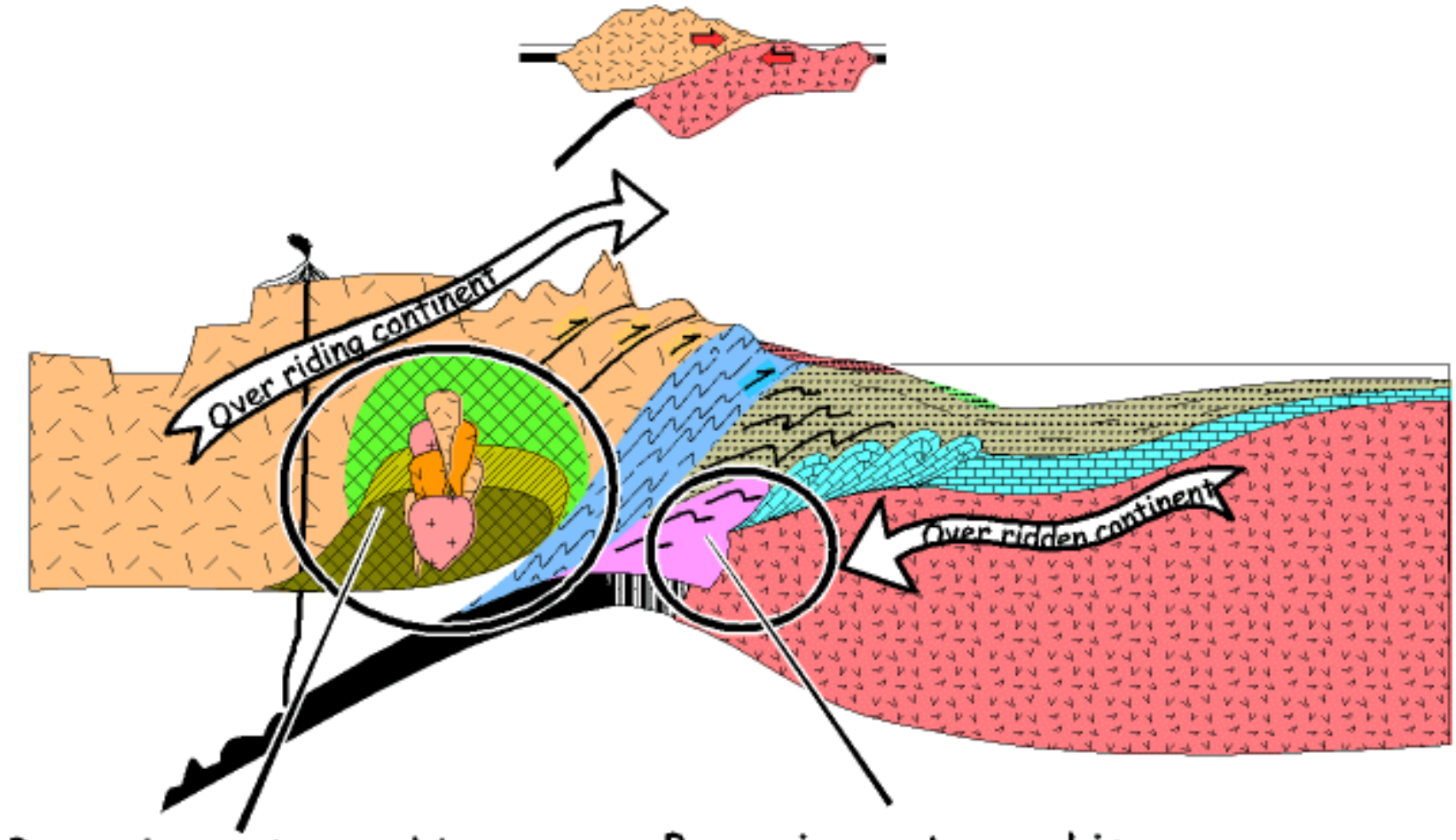


Continent-Continent Collision Orogeny

P 312


Former divergent continental margin with a sedimentary wedge undergoing a cordilleran mountain building
Trench and Melange Belt
Remnant Ocean Basin
Divergent Continental Margin
Subduction
Stage E on page 3
Suture Zone
HINTERLAND
FORELAND
Stage H on page 3

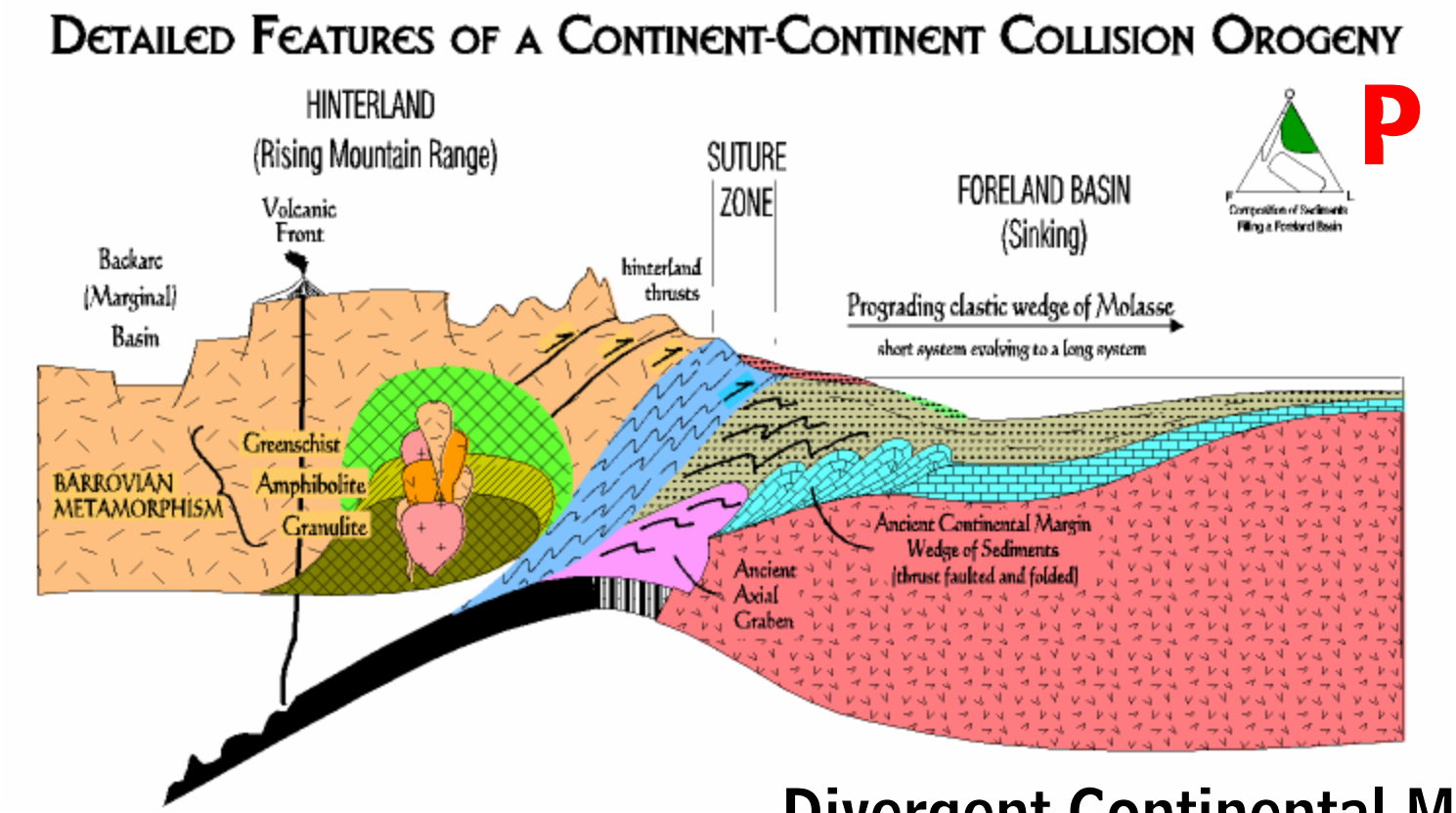
P 313



Barrovian metamorphism due to the intrusion of igneous batholiths.

Barrovian metamorphism due to burial under edge of over riding continent

Continent–Continent Collision Orogeny



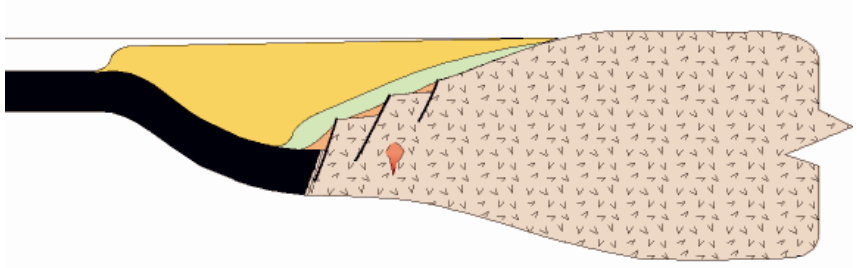
P 313

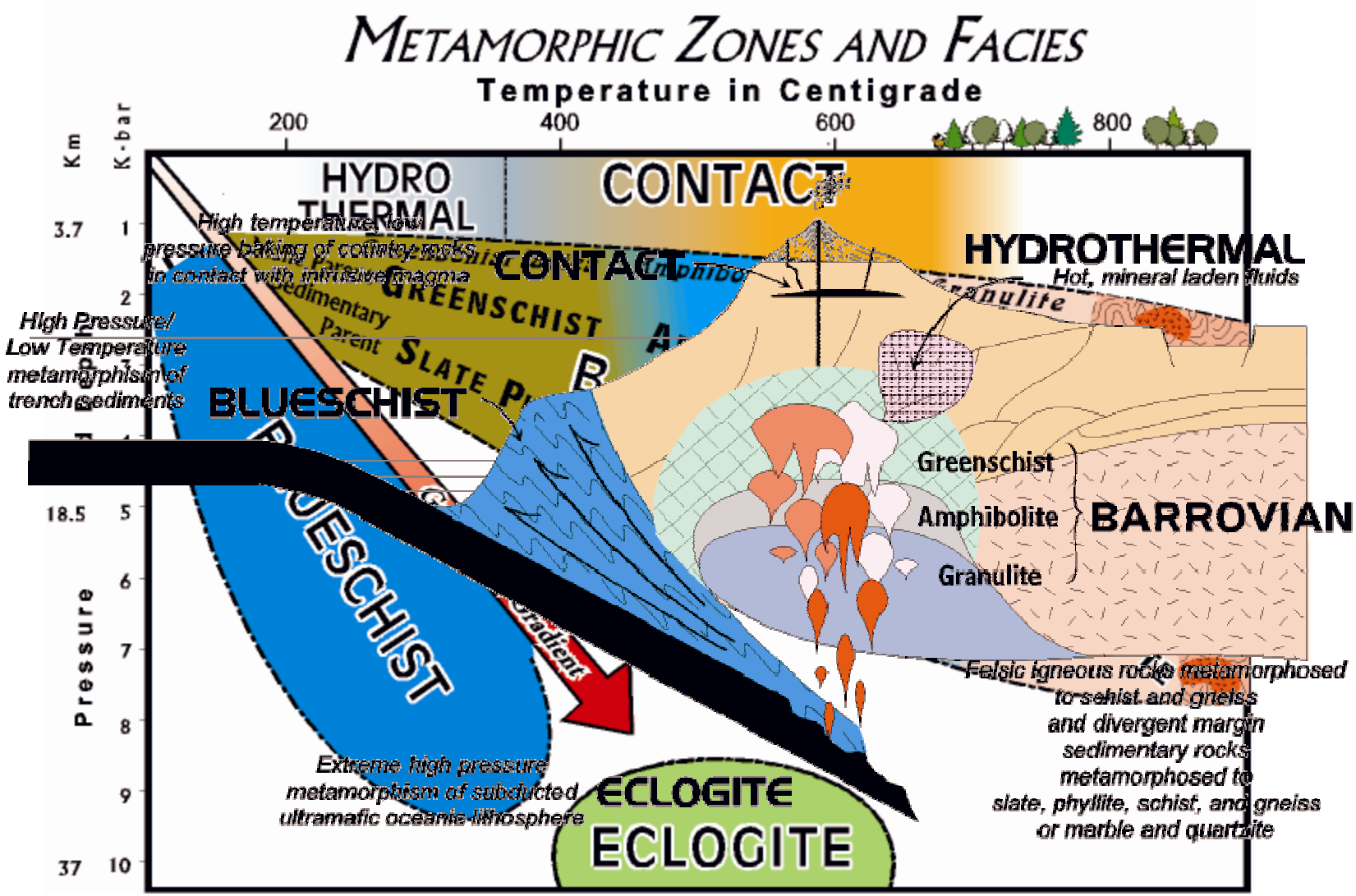
Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Divergent Continental Margin Sedimentary Wedge




METAMORPHIC ZONES AND FACIES
Temperature in Centigrade
200
400
600
800
Km
K-bar
3.7
18.5
37
Pressure
HYDRO THERMAL
CONTACT
High temperature, low pressure baking of country rocks in contact with intrusive magma
CONTACT
HYDROTHERMAL
Hot, mineral laden fluids
GREENSCHIST
Sedimentary Parent
SLATE
High Pressure/ Low Temperature metamorphism of trench sediments
BLUESCHIST
BLUESCHIST
Greenschist
Amphibolite
Granulite
BARROVIAN
Felsic igneous rocks metamorphosed to schist and gneiss and divergent margin sedimentary rocks metamorphosed to slate, phyllite, schist, and gneiss or marble and quartzite
Extreme high pressure metamorphism of subducted ultramafic oceanic lithosphere
ECLOGITE
ECLOGITE

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Shale

Clay
Silica
Iron oxides

Sedimentary
Bedding

Dull “thunk” sound when struck

Metamorphoses Into →

Slate

Small chlorite crystals

Slaty cleavage

Rings like a bell when struck

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

Texture Changes: bedding → slaty cleavage → schistosity → mineral banding

Rock Changes: shale → slate → phyllite → schist → gneiss

Slate

Small chlorite crystals

Slaty cleavage

Rings like a bell when struck

Metamorphoses Into

Phyllite

http://geology.about.com/library/bl/images/blphyllite.htm

Large chlorite crystals

Slaty cleavage – coarser grained foliation

Has a definite sheen in reflected light; back to dull “thunk” sound

Barrovian Metamorphism

Mineral Changes: clay → chlorite → quartz/feldspar/mica

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Phyllite

http://geology.about.com/library/bl/images/blphyllite.htm

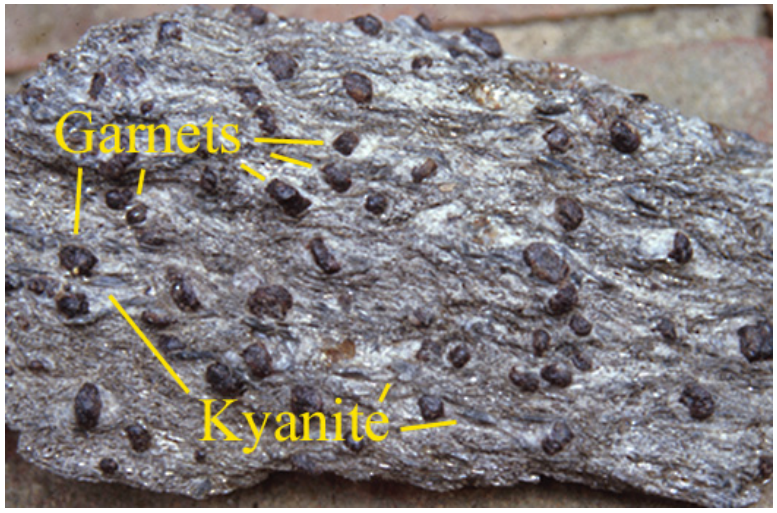
Large chlorite crystals

Slaty cleavage – coarser grained foliation

Has a definite sheen in reflected light; back to dull "thunk" sound

Metamorphoses Into

Schist



Chlorite gone. Quartz, feldspar, mica, and many new minerals

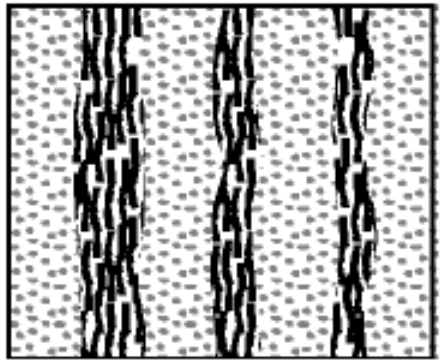
Schistosity; minerals completely intermixed

Minerals large enough to be easily identified

Foliated Textures – Mineral Banding

Banding

mica, qtz, feldspar



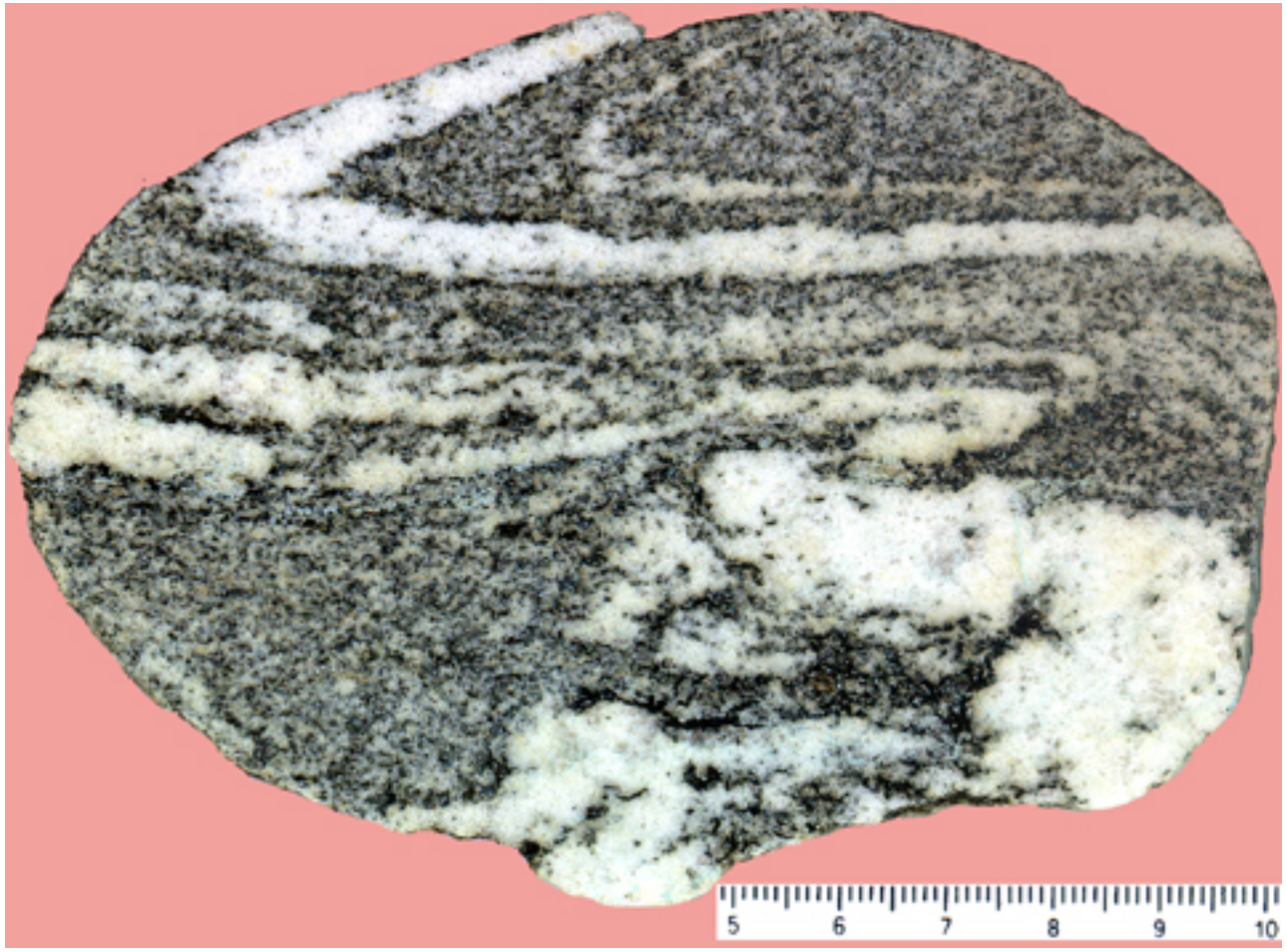
dark mafics (biotite/amphibole) segregate into bands separate from light colored qtz/feldspar

Gneiss

http://www.uwlax.edu/faculty/stoelting/Intro/Guides/Images2/gneiss_8X6.jpg

Foliated Textures – Mineral Banding

Gneiss



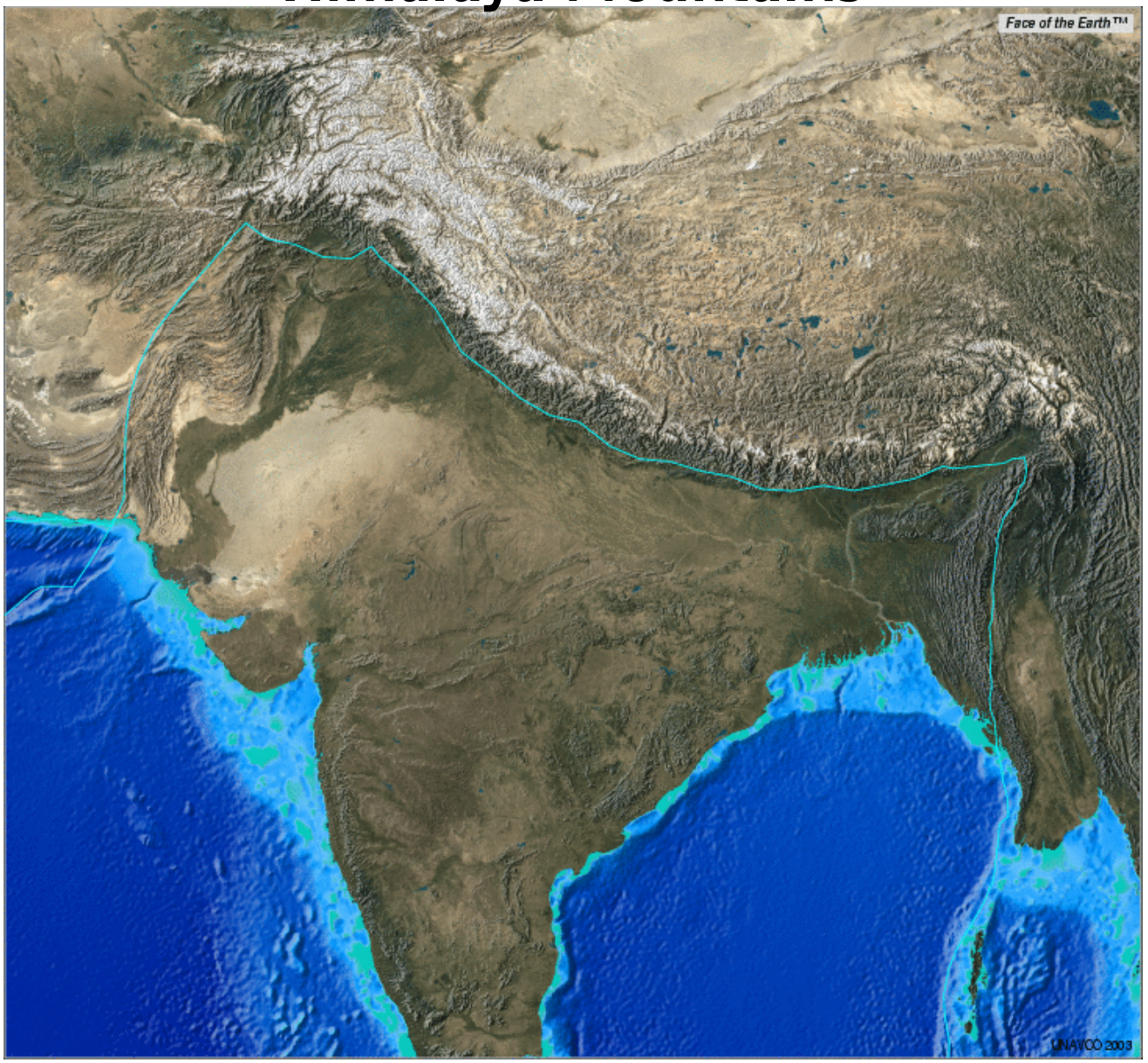
http://www.ut.ee/BGGM/miner/para_gneiss1.jpg

Foliated Textures – Mineral Banding

Gneiss

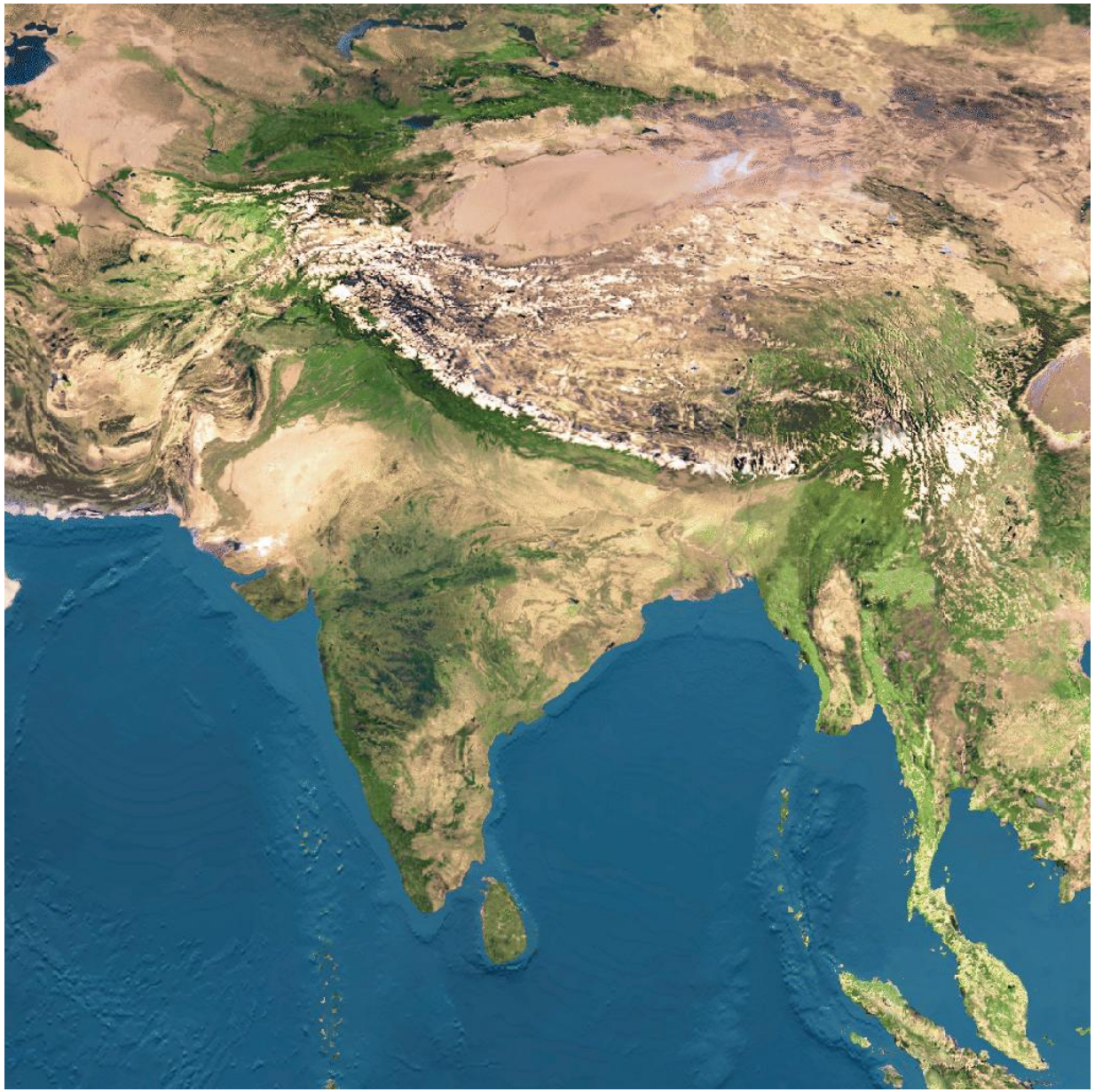
http://www.gly.uga.edu/railsback/FieldImages/BountifulFolds.jpeg

Continent–Continent Collision Orogeny
Himalaya Mountains



http://www.cliffshade.com/colorado/tectonics.htm

Continent–Continent Collision Orogeny

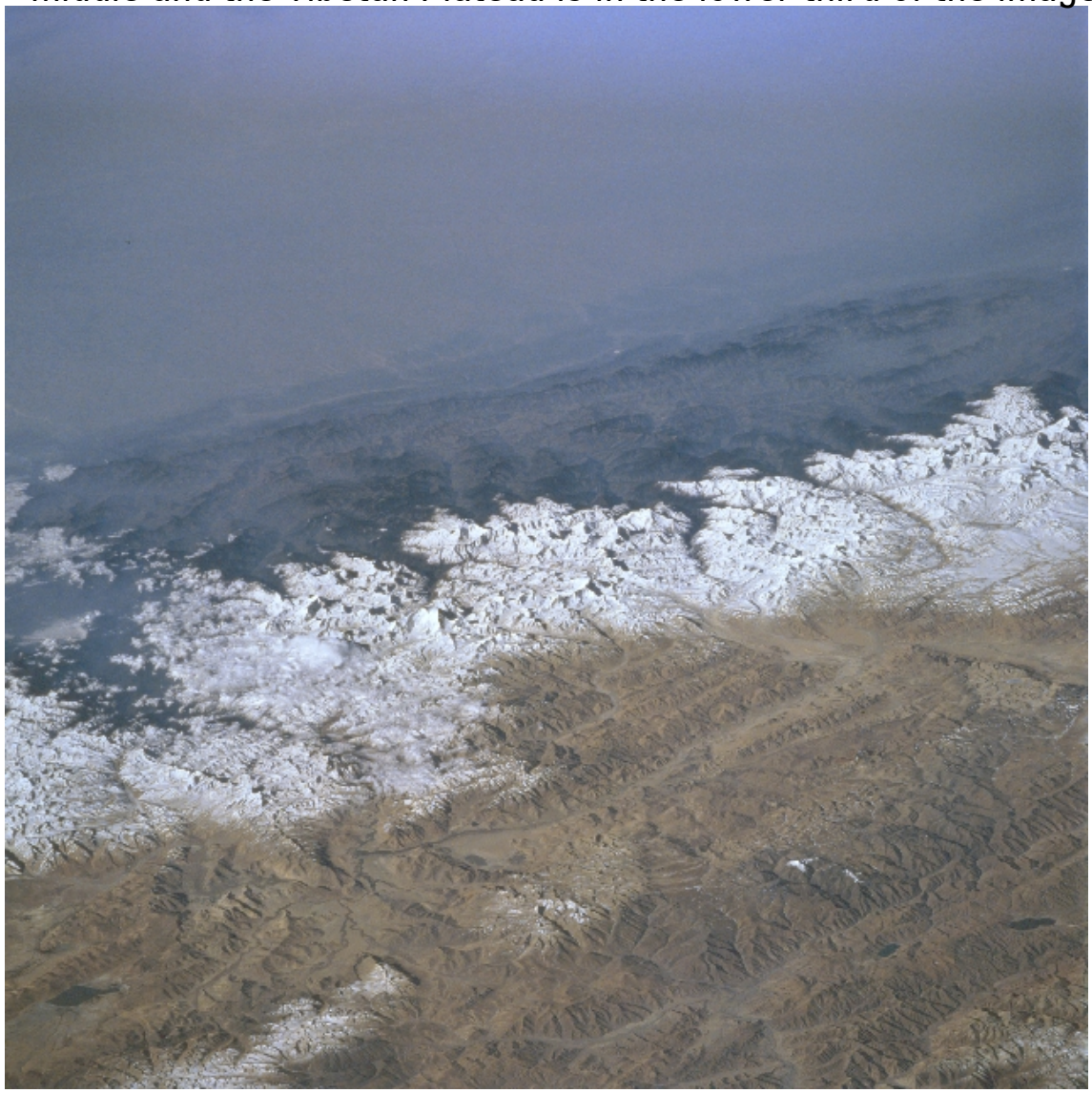


http://www.informatuttonet.com/atlante/

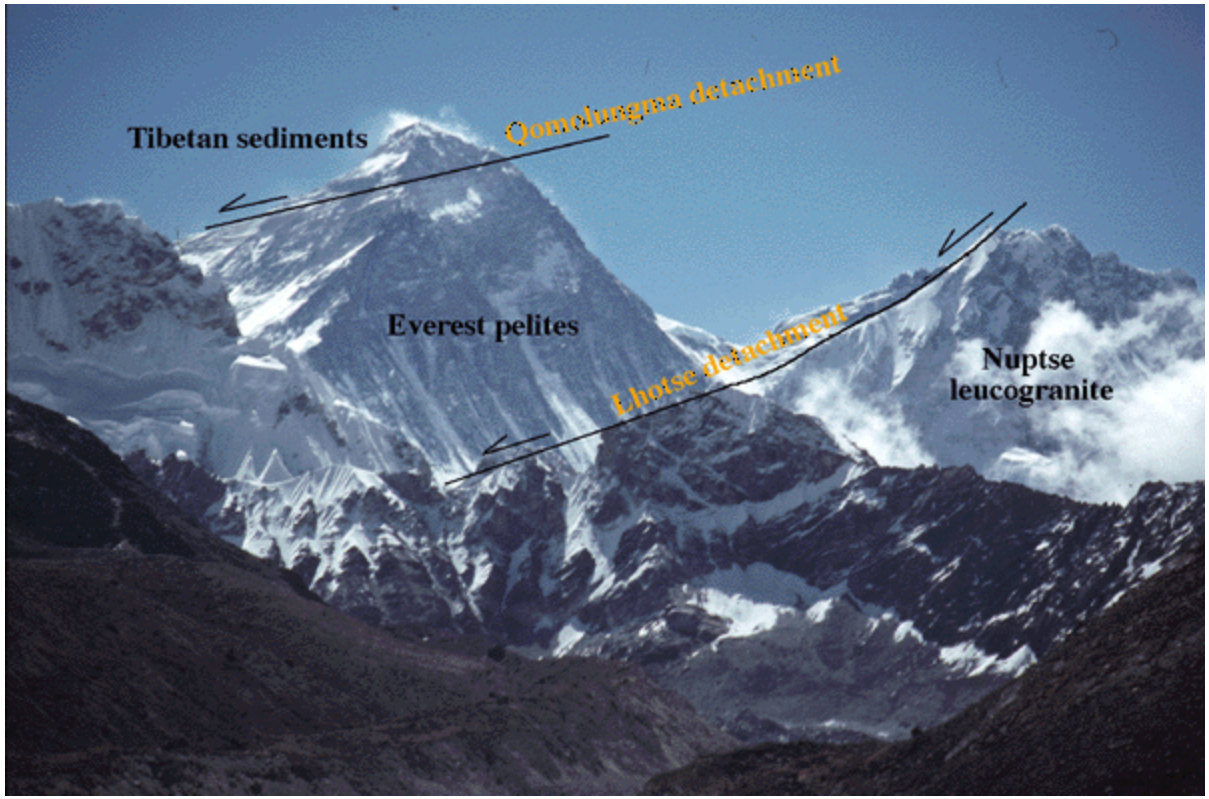
http://www.informatuttonet.com/atlante/homepage.htm

Continent–Continent Collision Orogeny

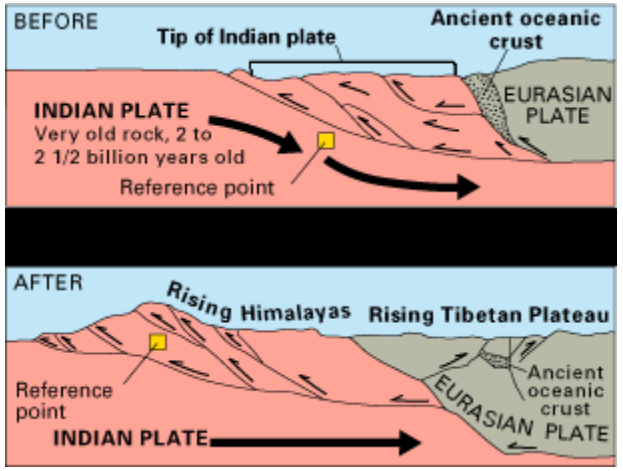
Himalaya Mountains. North central India is to the north (top) Nepal in the middle and the Tibetan Plateau is in the lower third of the image.



http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/earth_materials_structure/orders_of_relief.html



http://www.earth.ox.ac.uk/~mikes/EverestPhotos.html

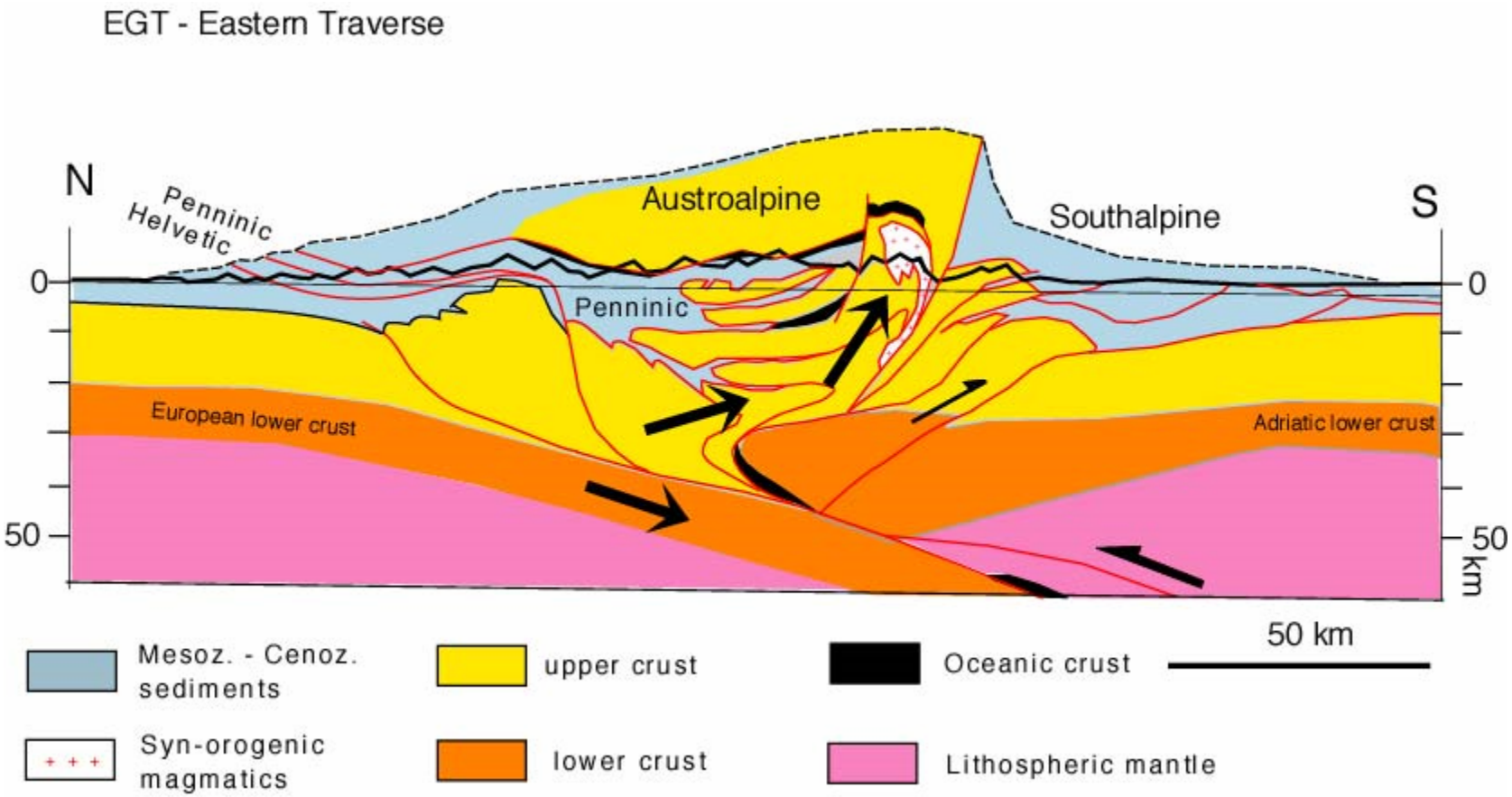


http://www.physicalgeography.net/fundamentals/10k.html

Swiss Alps

http://nths.newtrier.k12.il.us/academics/faculty/Munley/fun.htm

Deep Structure of the Swiss Alps: Nappe Structures



http://www.earthsci.unibe.ch/people/pfiffner/NRP20.html

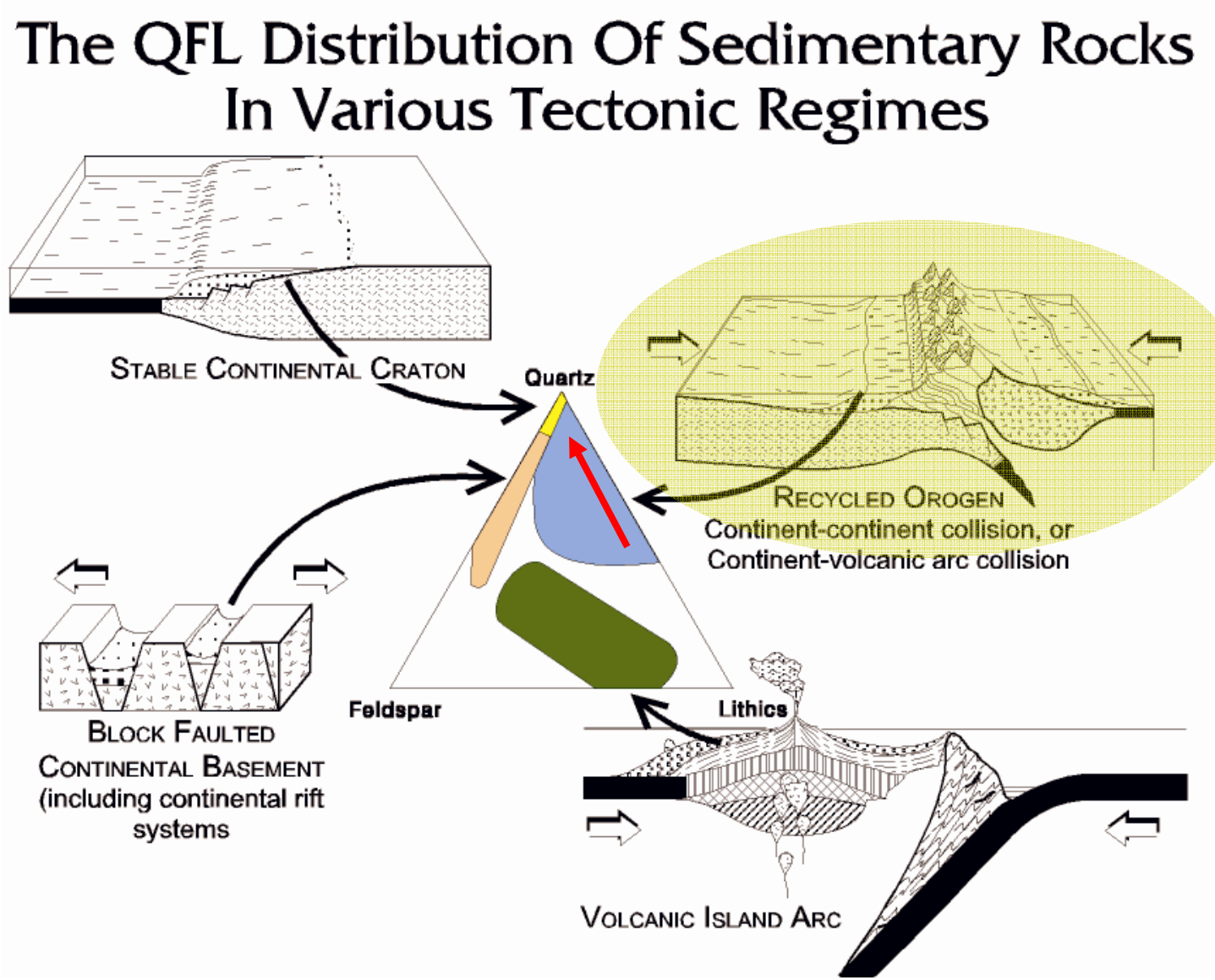
Deep Structure of the Swiss Alps: Nappe Structures

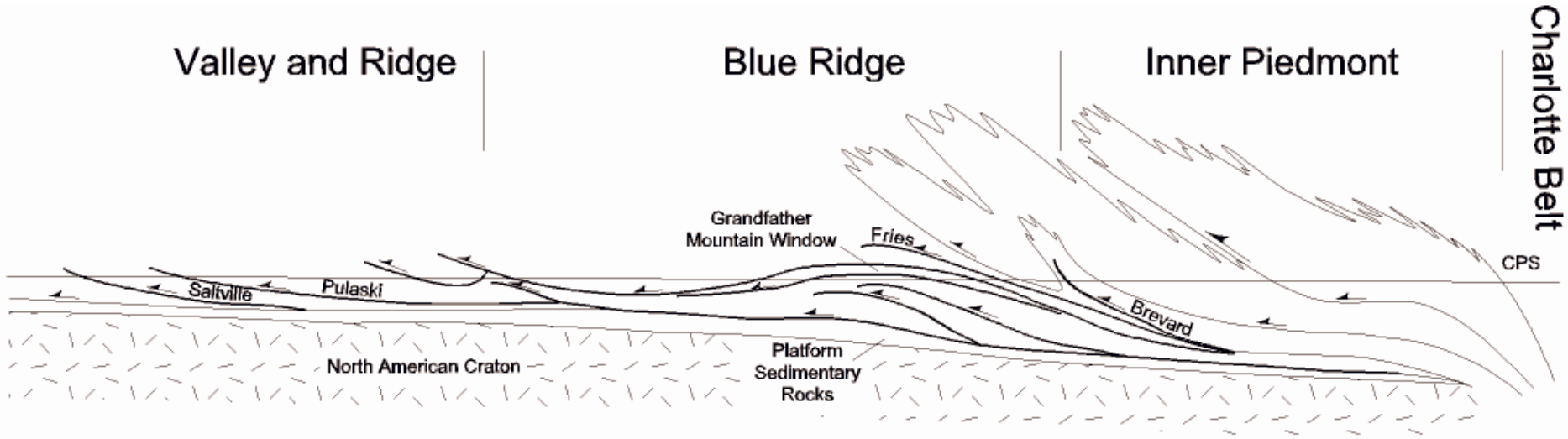
These folds are part of the Musconetcong Nappe within the Reading Prong nappe megasystem in Lehigh County, Pennsylvania.

http://www.dcnr.state.pa.us/topogeo/photogallery/images/eplerfold.jpg

Cycles Within Cycles

And, . . . Sedimentary Rocks Evolve . . .





NW-SE cross section through southern Virginia and North Carolina. Observe the large scale ductile folding in the piedmont region, and the brittle thrust faulting in the Valley and Ridge. From Hatcher, R.D., Jr., 1984, Southern and central Appalachian basement massifs, in Bartholomew, et.al. The Grenville Event in the Appalachians and Related Topics

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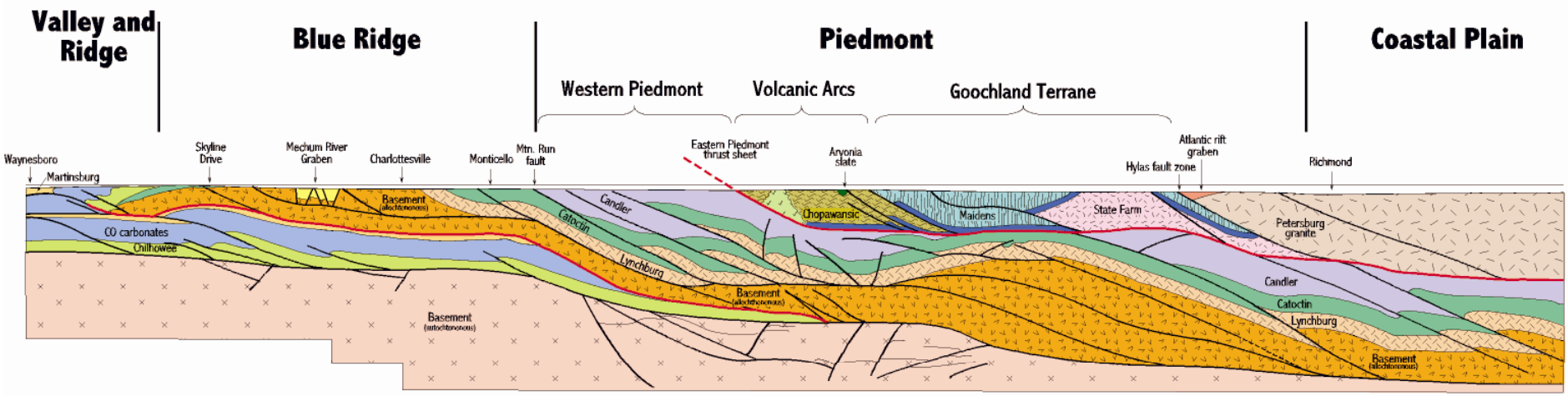
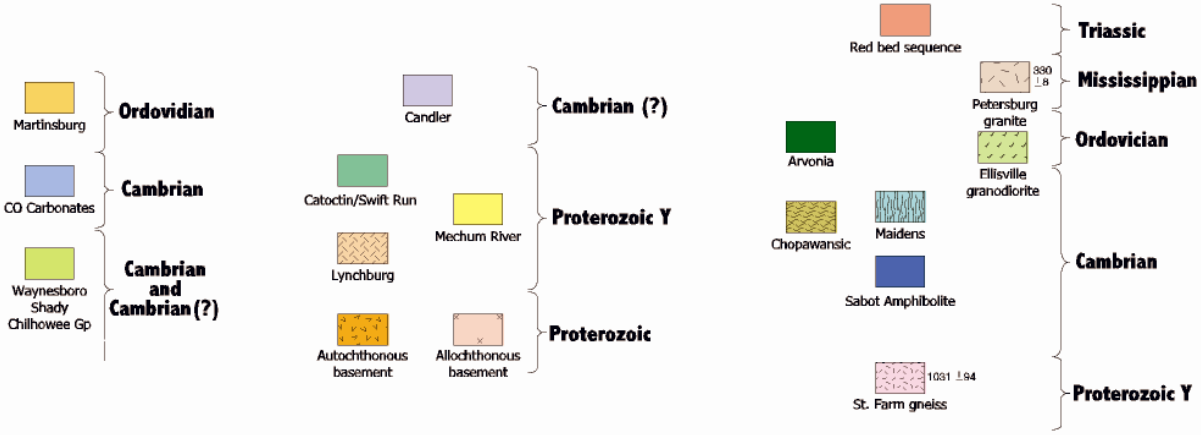
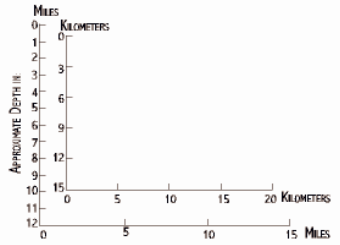
Interpretive Seismic Profile Along I-64 from the Valley and Ridge to the Coastal Plain in Central Virginia

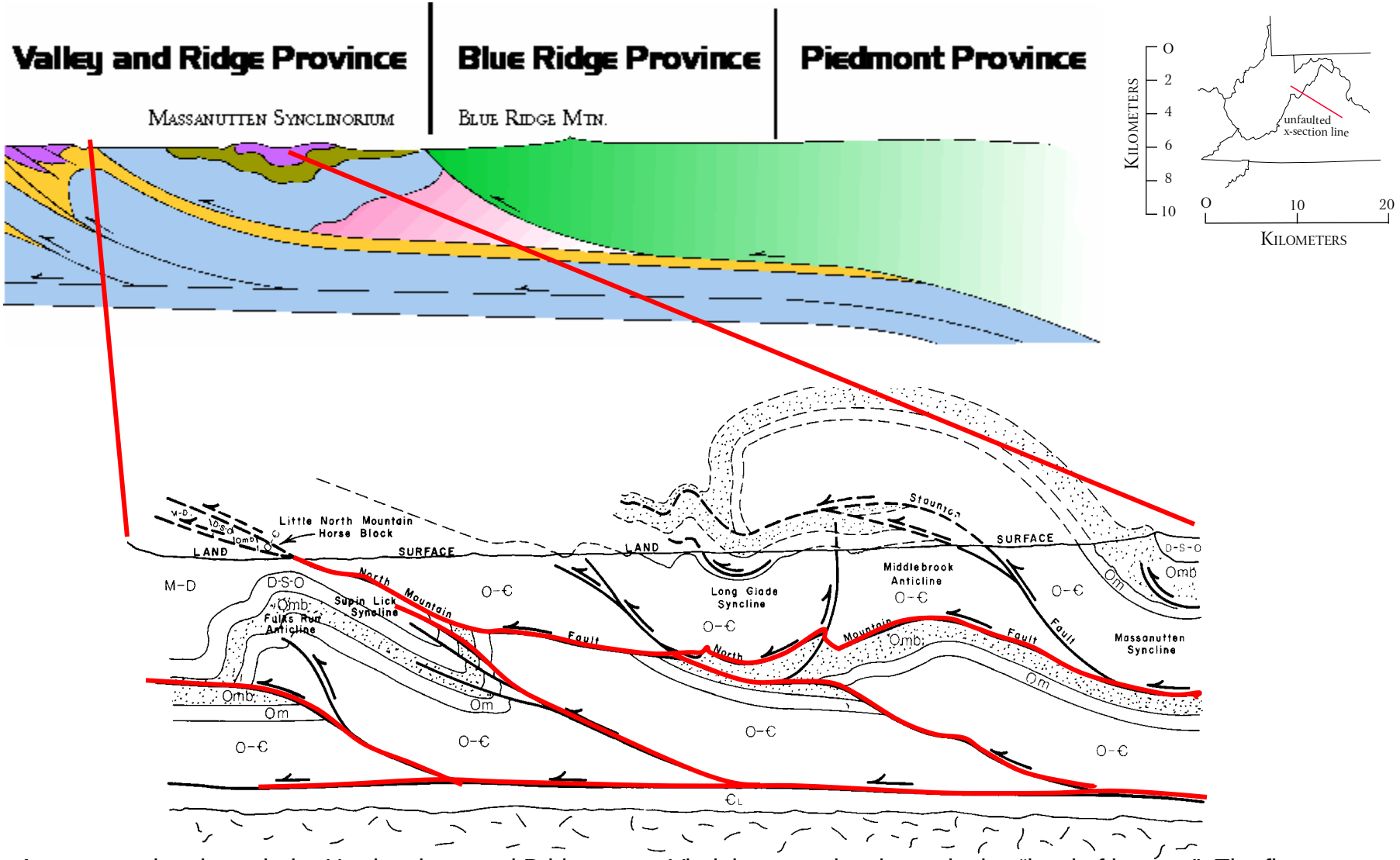




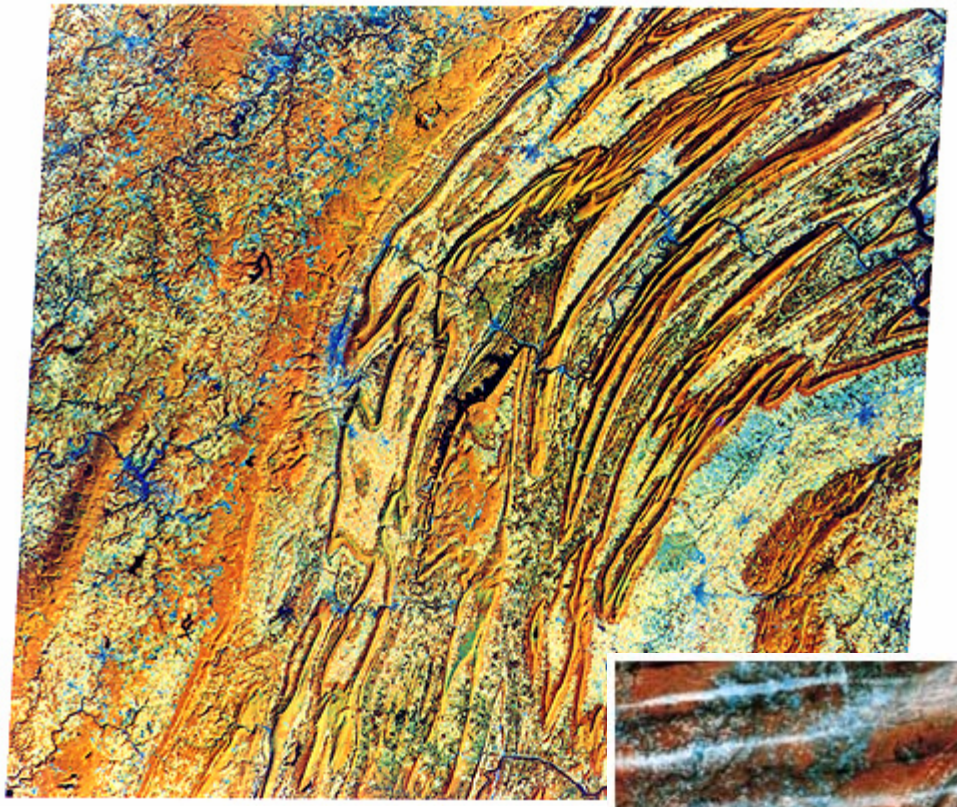


Redrawn and adapted from: Harris, Leonard D., and Wallace deWitt, Jr., and Kenneth C. Bayer, 1982. "Interpretive Seismic Profile Along I-64 from the Valley and Ridge to the Coastal Plain in Central Virginia, Department of the Interior, United States Geological Survey, Oil and Gas Investigations - Chart OC-123.

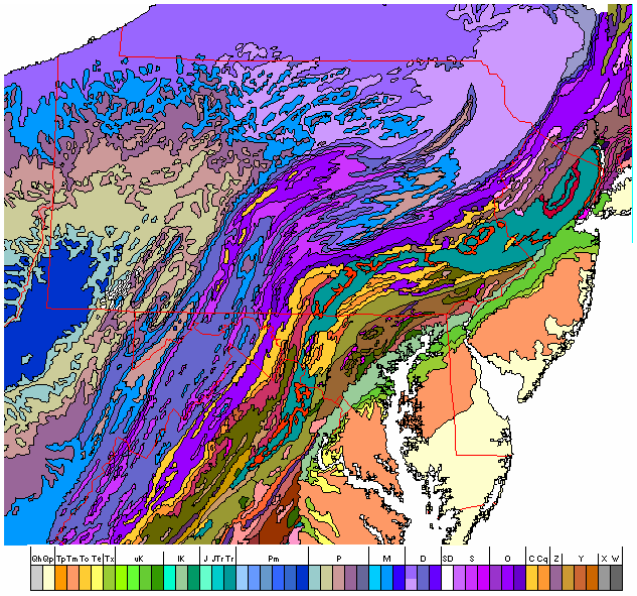
The Duplex Thrust System



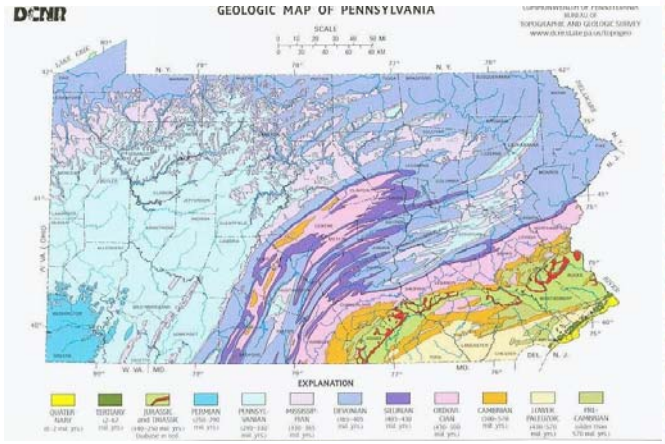
A cross section through the Harrisonburg and Bridgewater, Virginia area, showing a duplex “herd of horses.” The floor thrust is at the bottom of the drawing just above the basement rocks. The North Mountain fault is the roof thrust. In between are a series of splay faults that isolate a series of horses. Note the overturned anticline on the far left (west) side where the last ramp formed. From Gathright and Frischmann, 1986, Geology of the Harrisonburg and Bridgewater Quadrangles, Virginia.

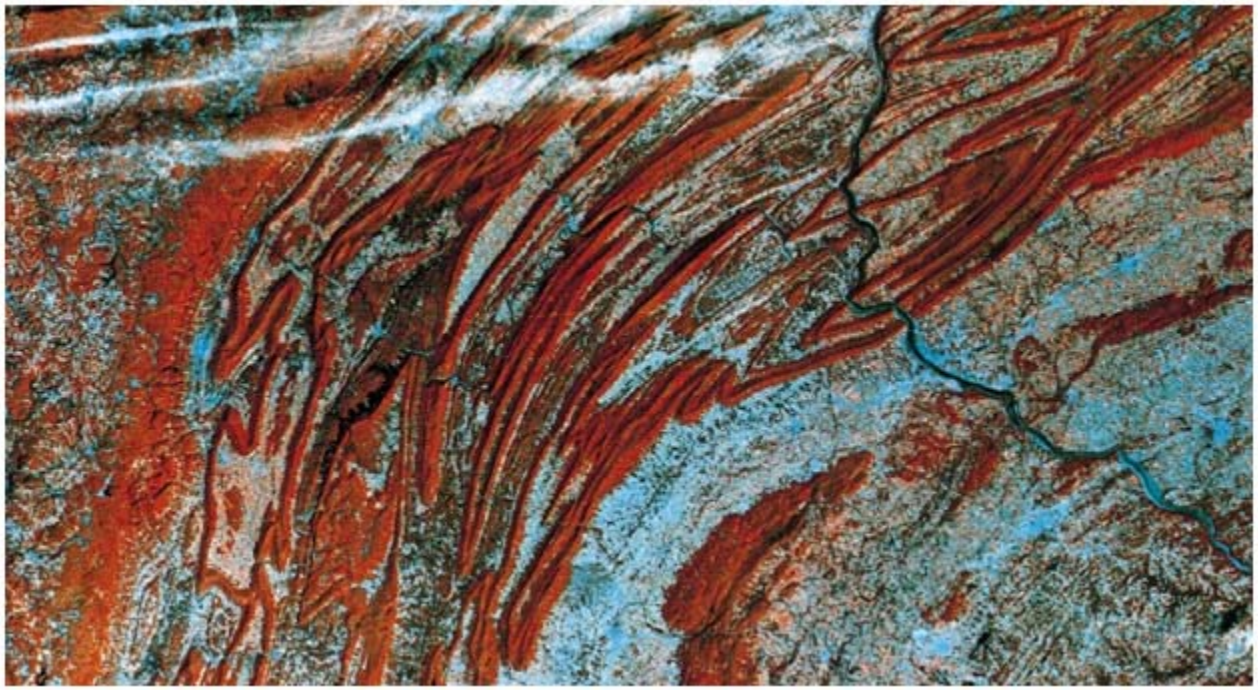


http://rst.gsfc.nasa.gov/Sect6/Sect6_3.html



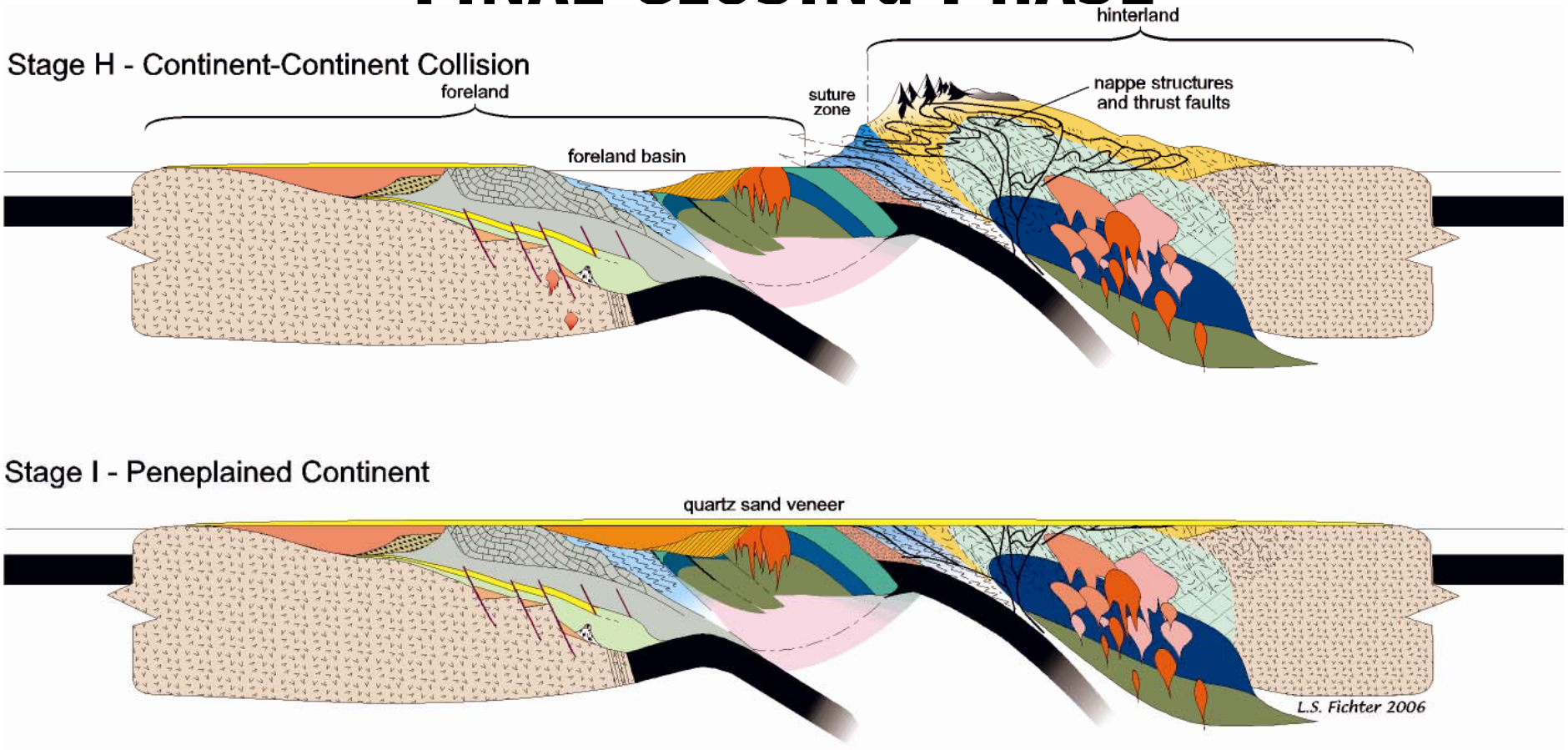
http://www.uwgb.edu/dutchs/StateGeolMaps/PaNJGMap.HTM





http://earth.geol.ksu.edu/sgao/g100/plots/

Wilson Cycle
Final Closing Phase



Continent-Continent Collision Orogeny

Peneplained Continent

http://www.informatuttonet.com/atlante/homepage.htm

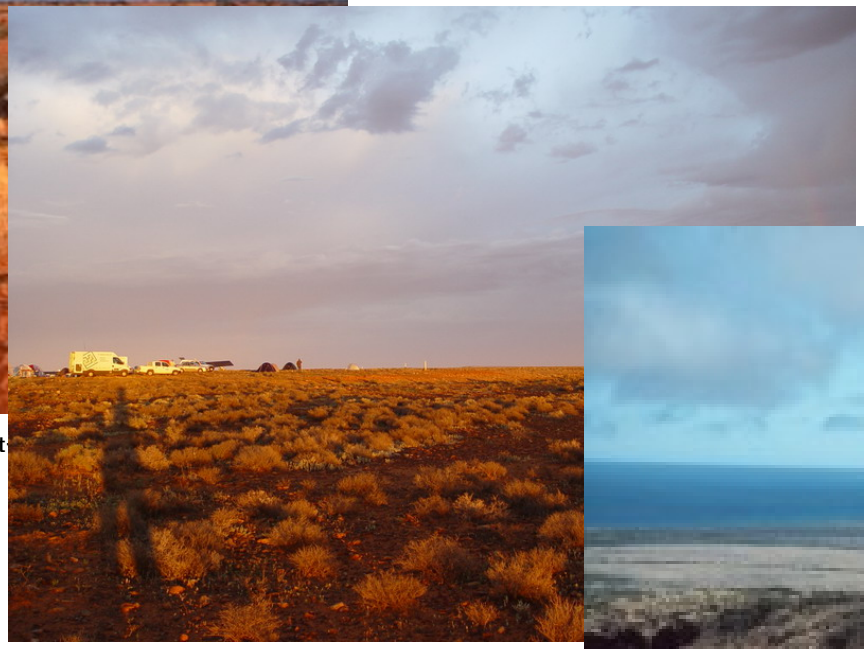
http://www.informatuttonet.com/atlante/

Peneplained Continent

The Australian Outback

The area known as the Australian Outback, has no boundaries, nor locality. It is a place engendered by the human spirit. A place deep within ourselves, where we instinctively recognize ourselves as being a primeval soul and at-one with nature; or in conflict with our world. Places known as 'The Outback' are many in Australia. They cover vast regions. However the one thing which they have in common is a sense of isolation, a sense of being a mere, small creature in the greater scheme of things. They are places where the laws of the land are muted by the demands of survival. This is 'The Outback' and it is what strikes the greatest awe, or fear within the heart of the civilized individual.

http://www.australianbedandbreakfast.com.au/nsw-act



http://www.edc.uri.edu/lme/text/n-australian.htm

http://www.edc.uri.edu/lme/text/n-australian.htm

Peneplained Continent

http://www.angelarossen.com/exhibits/large/towards_nanutarra_large.htm

http://www.blm.gov/wildlife/pl_87sum.htm

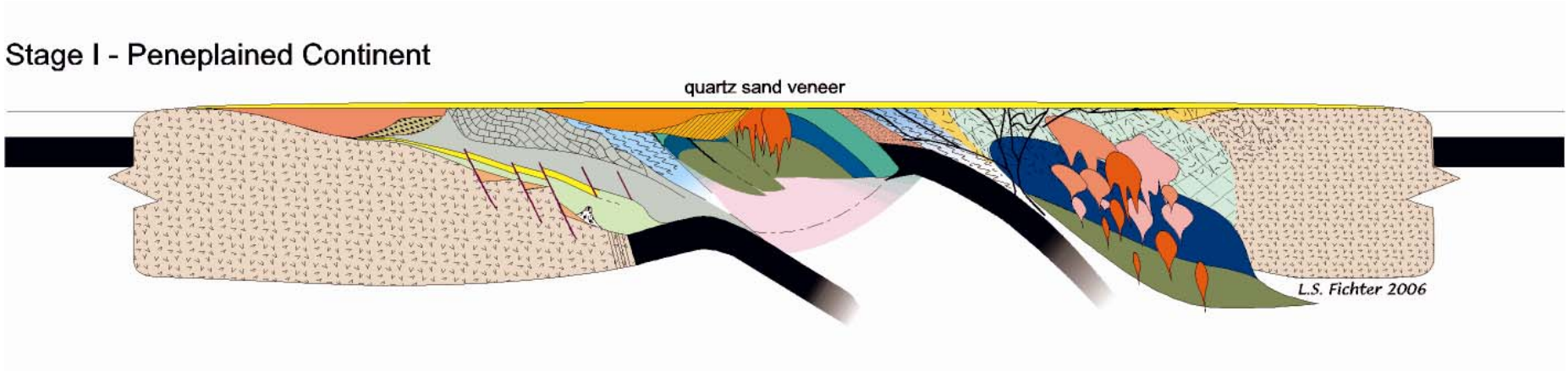
http://www.cpfieldinstitute.org/images/cpinfo/colorado_plateau.jpg

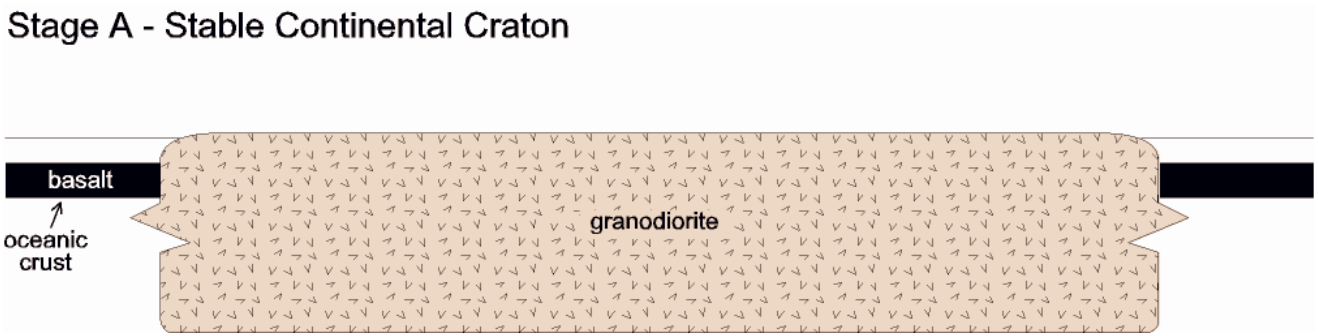
http://www.gdargaud.net/Climbing/GrandCanyon.html

http://www.snowcrest.net/swick/grand_canyon/precam1.htm


http://3dparks.wr.usgs.gov/joshuatree/html2/e90.htm

Wilson Cycle
Compare and Contrast





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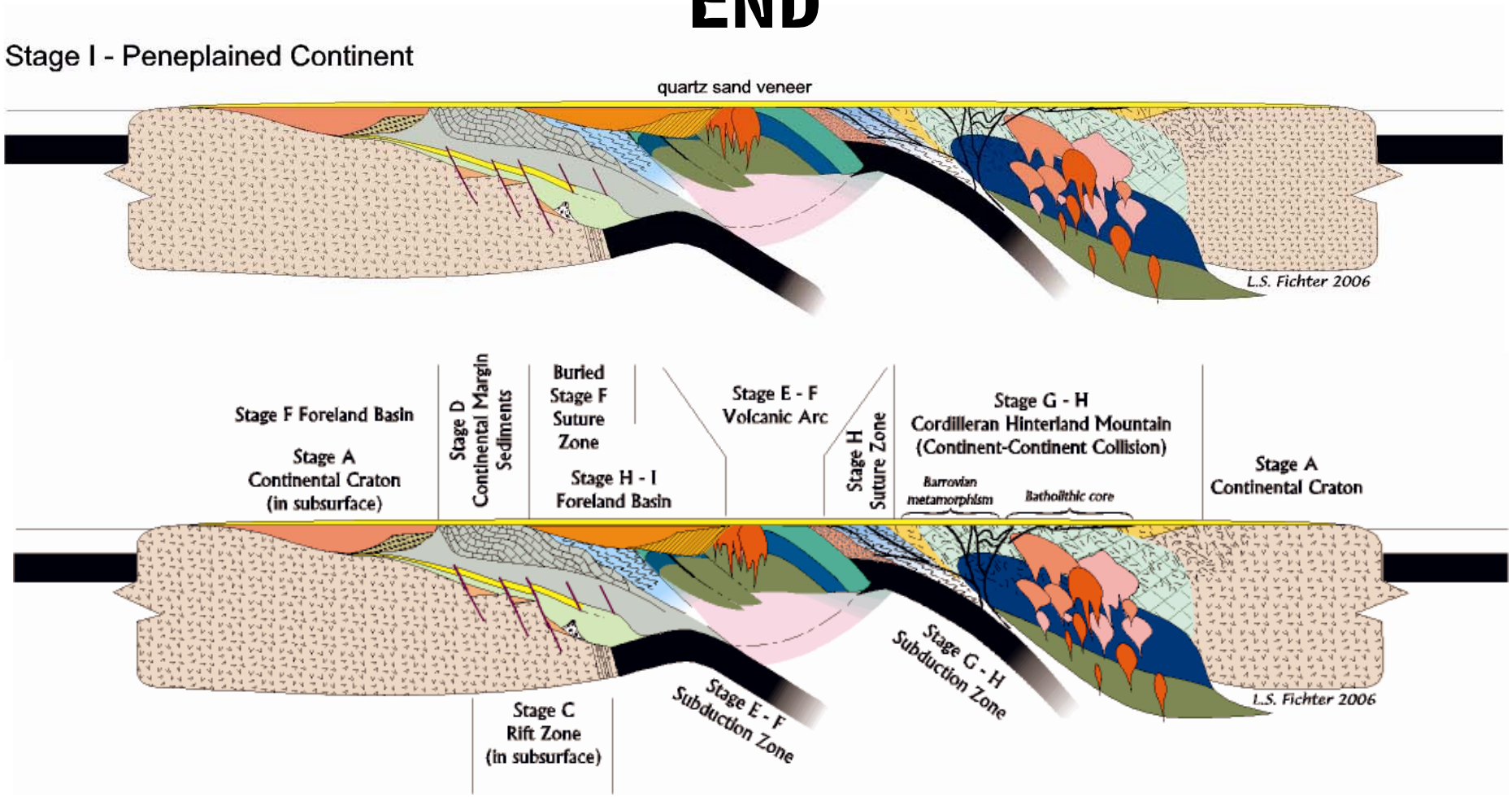
Wilson Cycle
End



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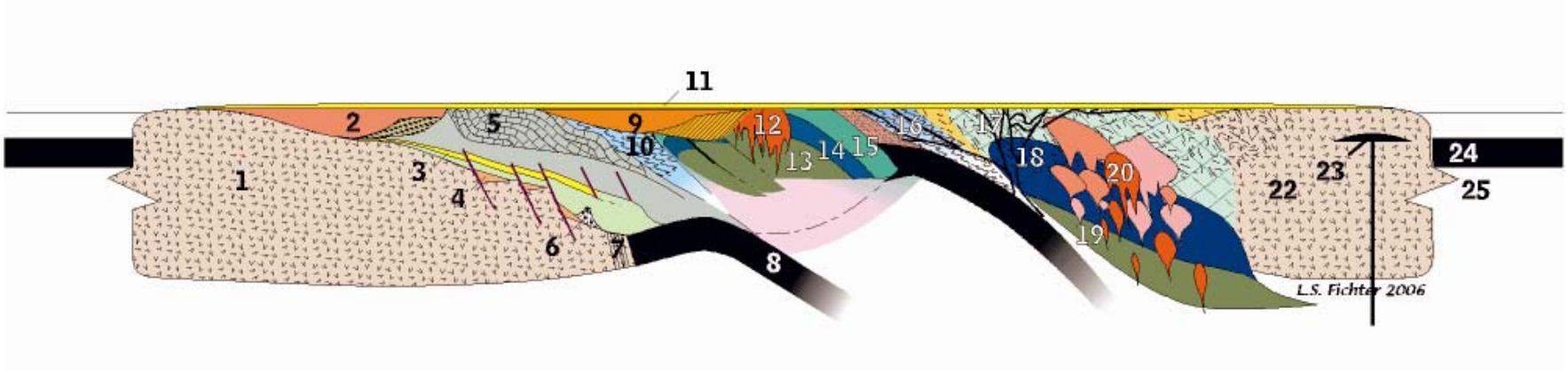
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L.S. Fichter 2006