

**Cascadia EarthScope
Earthquake and Tsunami
Education Program (CEETEP)**

**Beauty and the Beast:
Plate Tectonics and
Geological Hazards of
the Pacific Northwest**

Robert J. Lillie

*Otter Crest State Scenic Viewpoint,
Oregon*



Goal and Objectives CEETEP Training Workshop

Goal: To provide coastal educators with background knowledge, strategies, and materials to engage students and visitors on the science of, and preparedness for, earthquakes and tsunamis.

Objectives. Participants will be able to:

- 1. Explain how the landscape of western Oregon formed.**
- 2. Discuss geological hazards of the Oregon Coast.**
- 3. Incorporate the region's geological landscape and geophysical monitoring into lesson plans and interpretive programs that tell the story of the Coast's formation and potential for earthquakes and tsunamis.**





Big Ideas:

1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.

2. Earth is 4.6 billion years old.

3. Earth is a complex system of interacting rock, water, air, and life.

4. Earth is continuously changing.

5. Earth is the water planet.

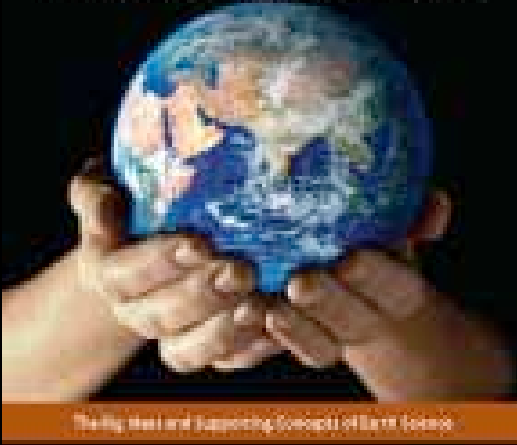
6. Life evolves on a dynamic Earth and continuously modifies Earth.

7. Humans depend on Earth for resources.

8. Natural hazards pose risks to humans.

9. Humans significantly alter the Earth.

EARTH SCIENCE
LITERACY PRINCIPLES



The Big Ideas and Supporting Concepts of Earth Science

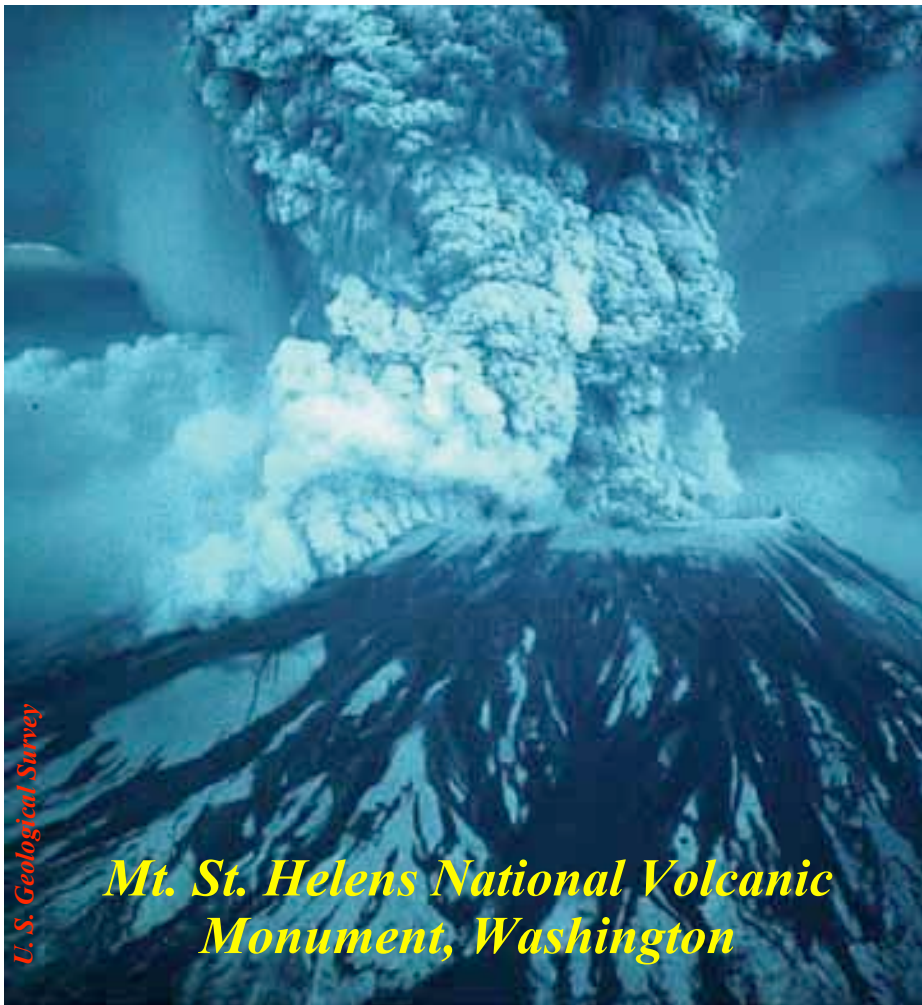
www.earthscieliteracy.org



Beauty and the Beast



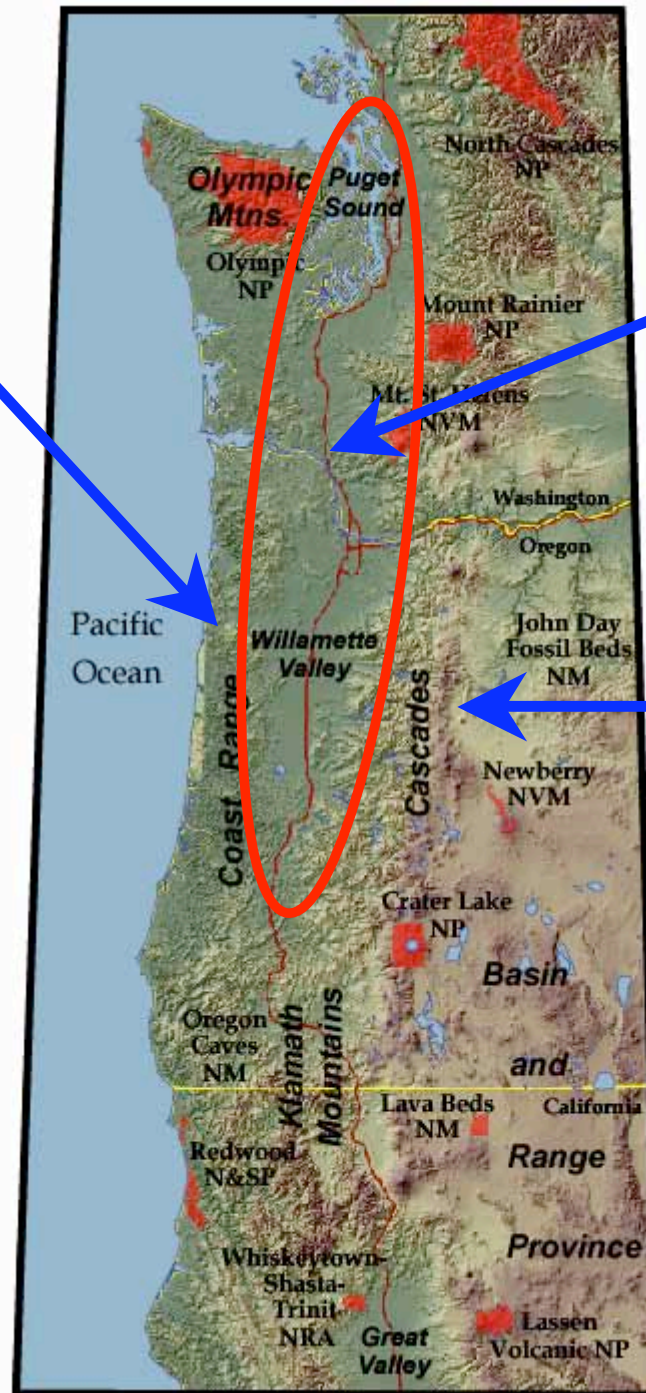
“The same geological processes that threaten our lives with earthquakes and volcanic eruptions also nourish our spirits by creating the spectacular mountains, valleys, and coastlines of the Pacific Northwest.”



Coastal Ranges

1. Why are there two parallel mountain ranges in the Pacific Northwest?

2. Why are there earthquakes, tsunamis and volcanic eruptions?



Most of the People

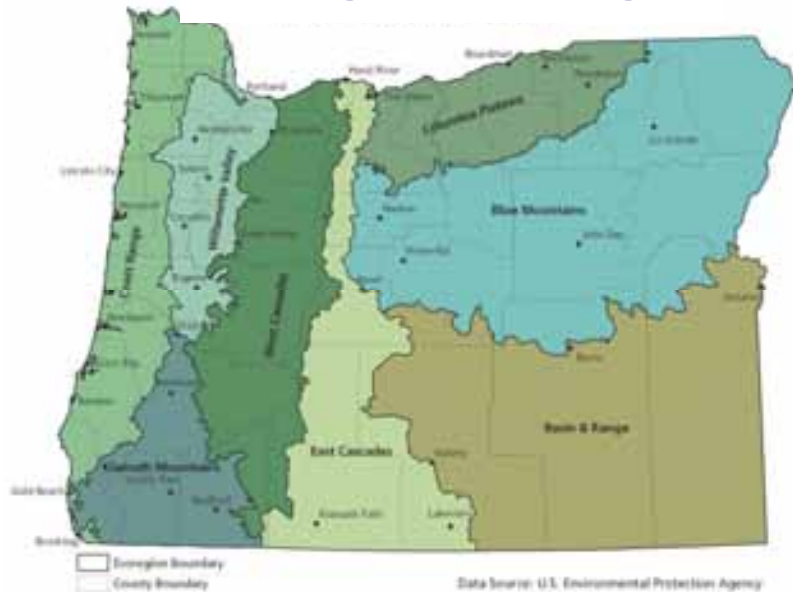
Cascade Volcanoes

**National Park
Lands in the
Pacific Northwest**

Making Connections:

Oregon's ecology is closely tied to Oregon's geology.

Ecoregions of Oregon

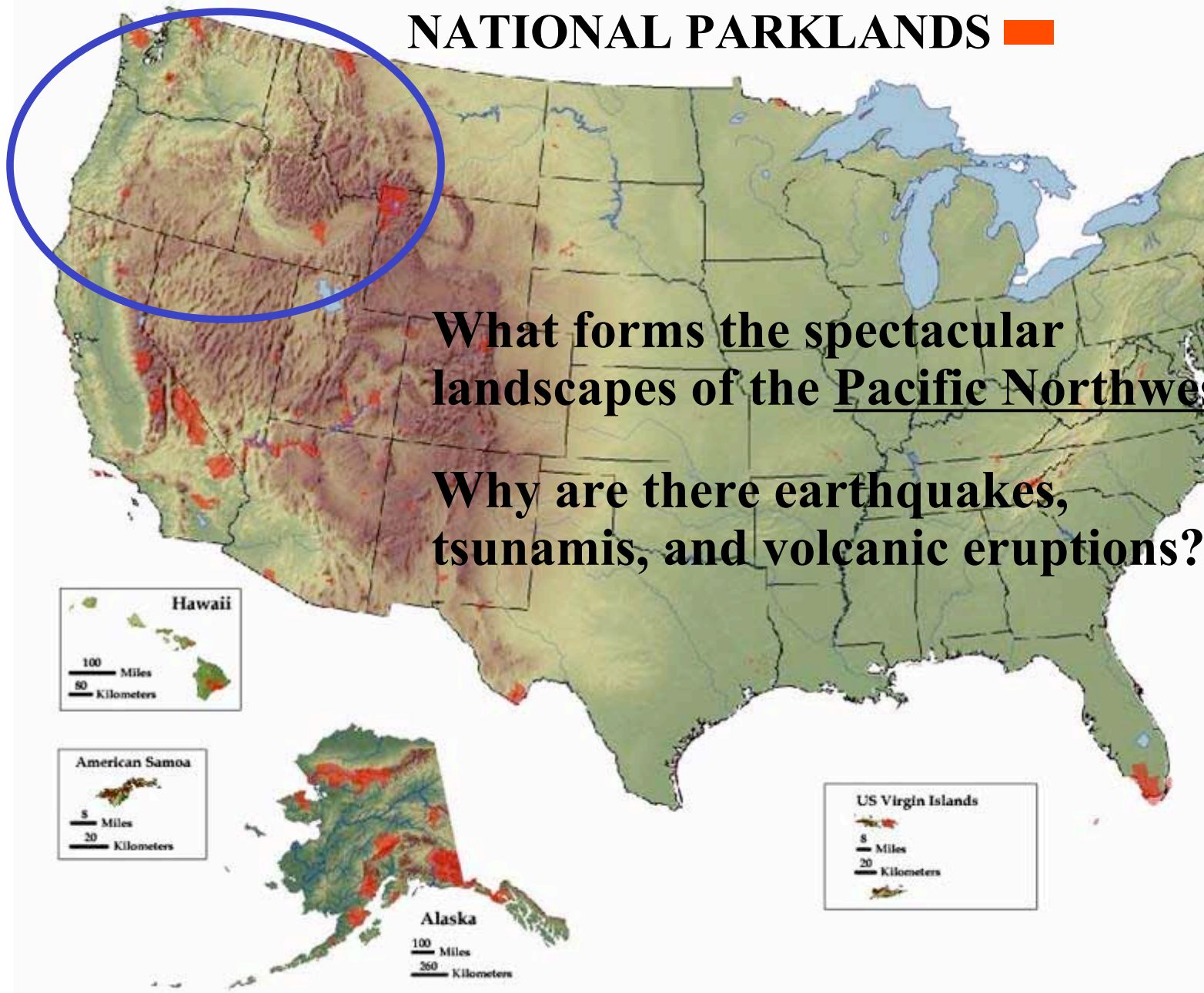


Geologic Provinces of Oregon



E. L. Orr and W. N. Orr, "Geology of Oregon,"
Kendall/Hunt Pub. Co., 5th Edition, 1992.

NATIONAL PARKLANDS



What forms the spectacular landscapes of the Pacific Northwest?

Why are there earthquakes, tsunamis, and volcanic eruptions?





Cracked Egg Shell!

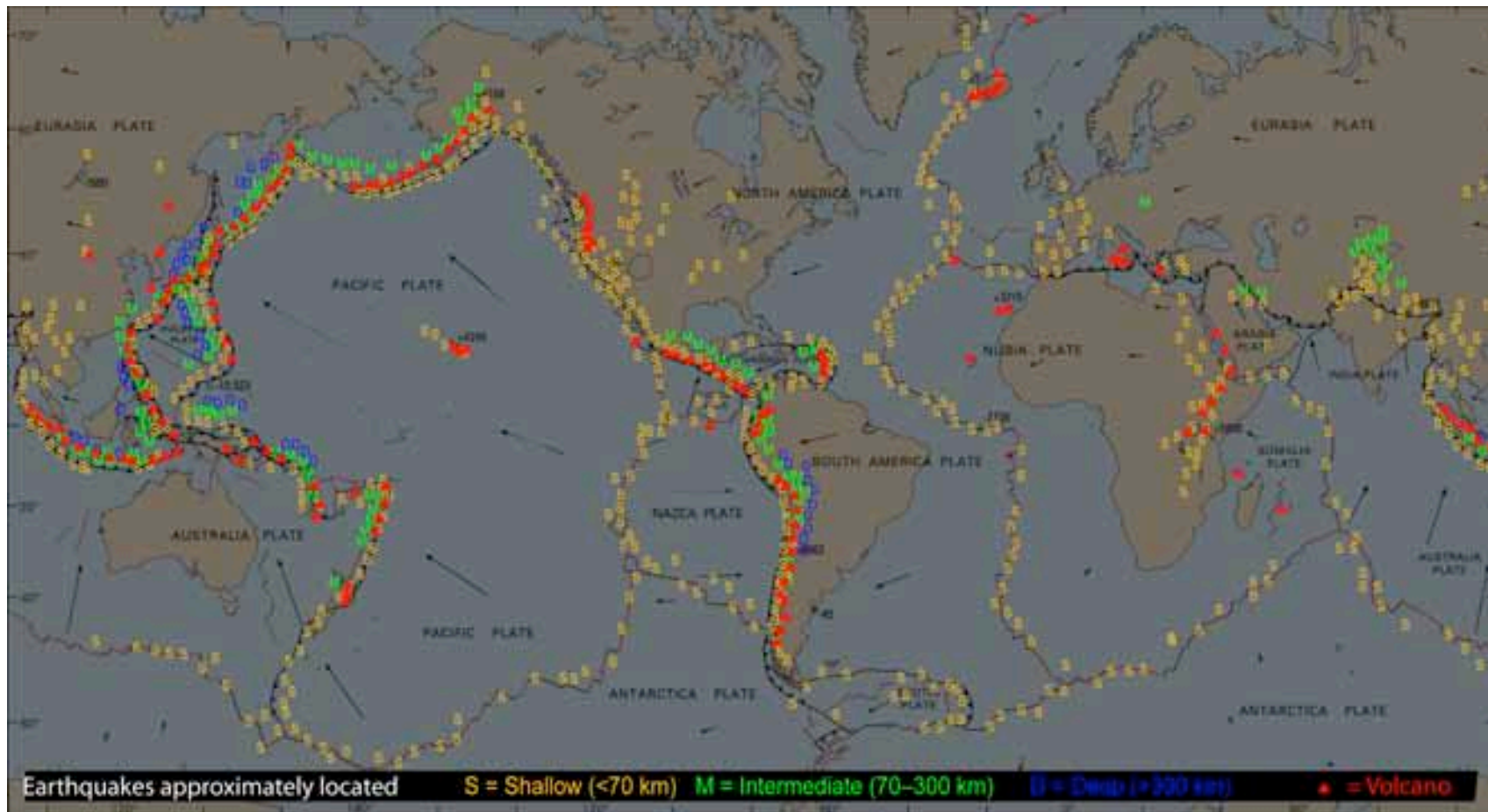


Divergent \
 Convergent ← "Teeth" on Overriding Plate
 Transform \

Plate Boundaries

Plate Tectonics: Earthquakes and Volcanoes

- Most volcanoes and earthquakes occur along plate boundaries.
- The deeper quakes (green and blue) occur where one plate dives beneath another (subduction zones).
- Pacific “Ring of Fire”



Modified from USGS Graphics and Lillie, 2005, "Parks and Plates"

PLATE BOUNDARIES

- Divergent:

- Plates move away from one another.
- Volcanoes and Shallow Earthquakes



- Convergent:

- Plates move toward one another.
- Volcanoes and very large earthquakes



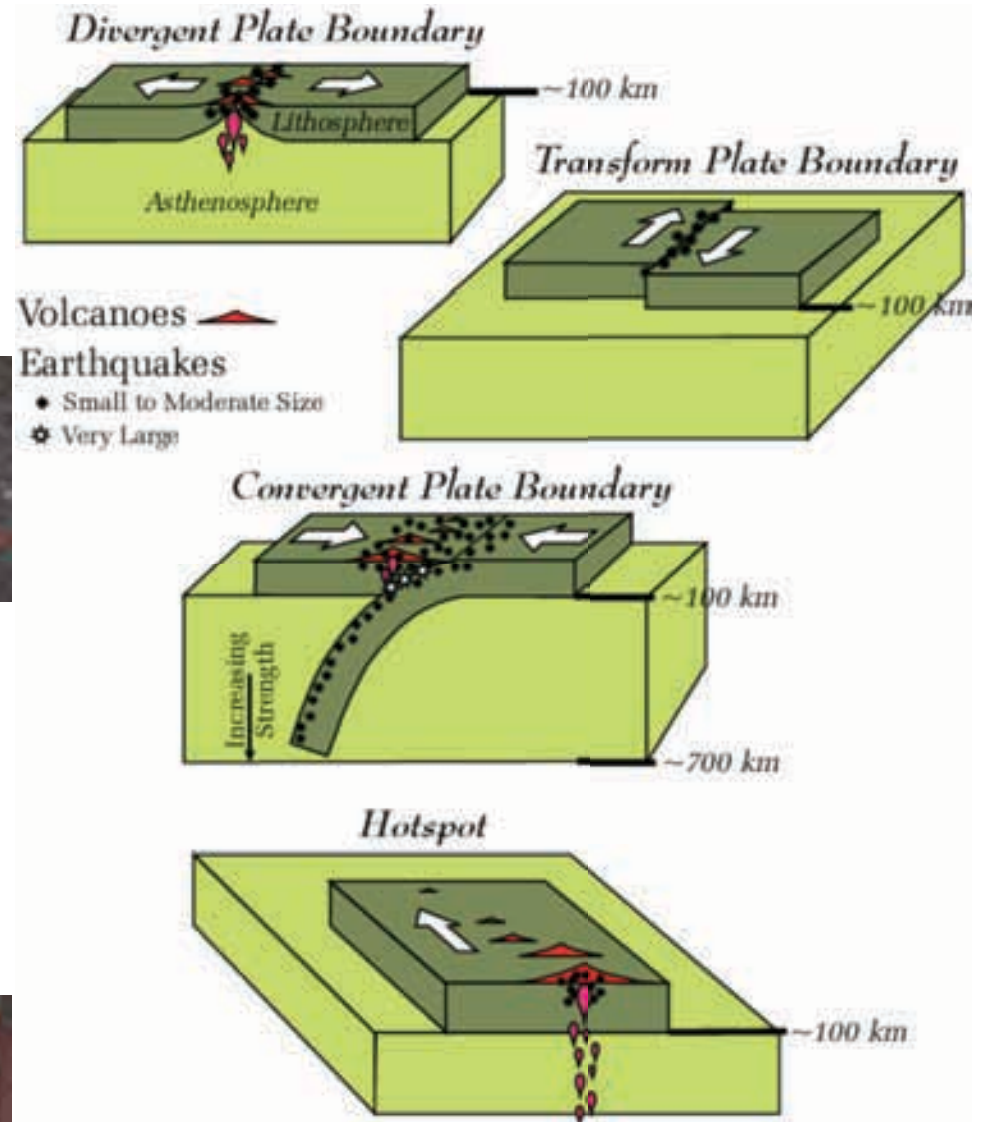
- Transform:

- Plates slide past one another.
- Earthquakes but no volcanoes



- (Hotspot):

- Plate rides over plume of hot mantle.
- Lots of volcanism.



*Convergent Plate Boundary
(Subduction Zone)*

Hotspot (Mantle Plume Head)

Cascadia

**Columbia
Plateau**

Coast Range

Willamette
Valley

Cascade
Volcanoes

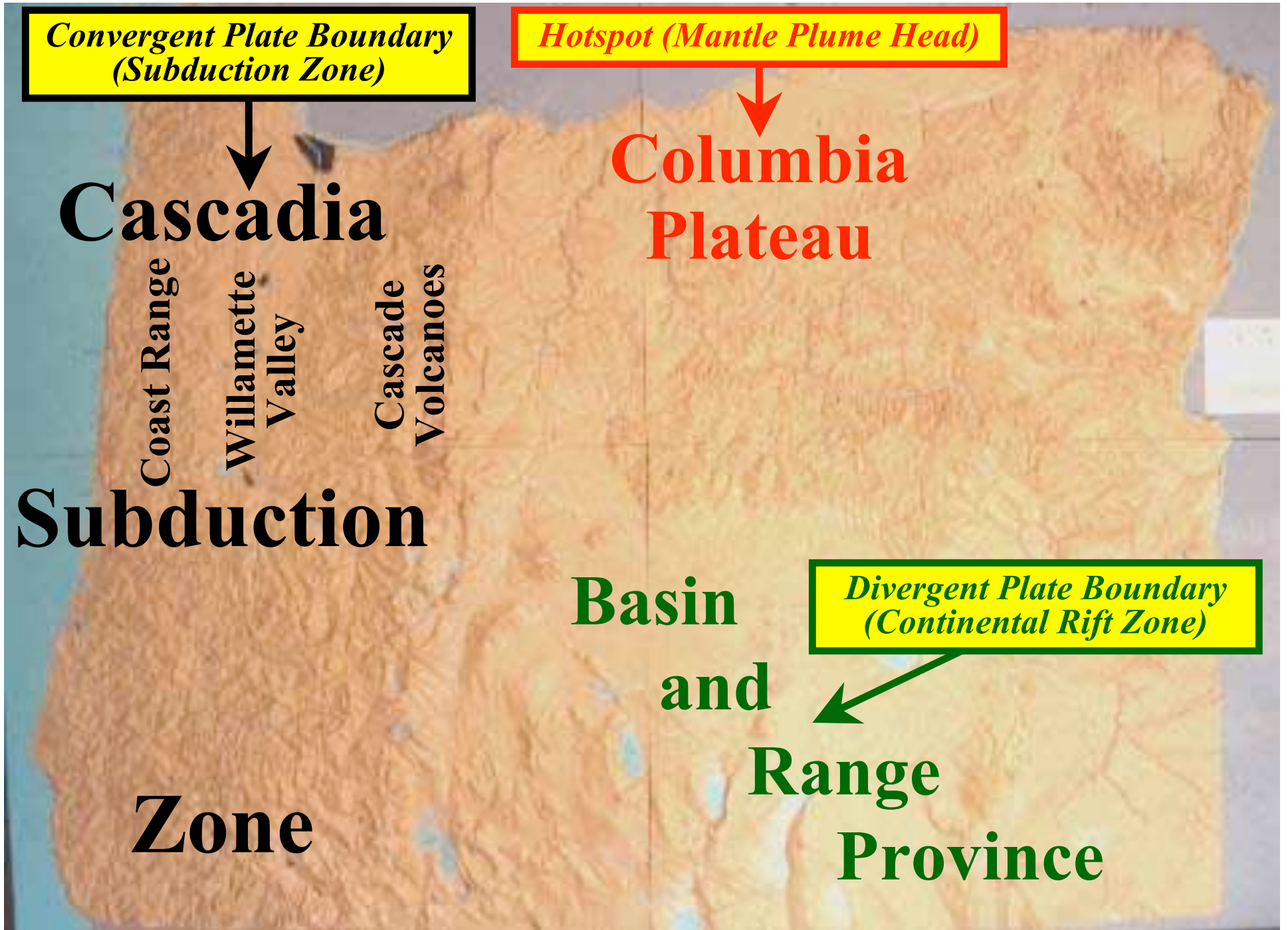
**Subduction
Zone**

**Basin
and
Range
Province**

*Divergent Plate Boundary
(Continental Rift Zone)*

Zone

Province

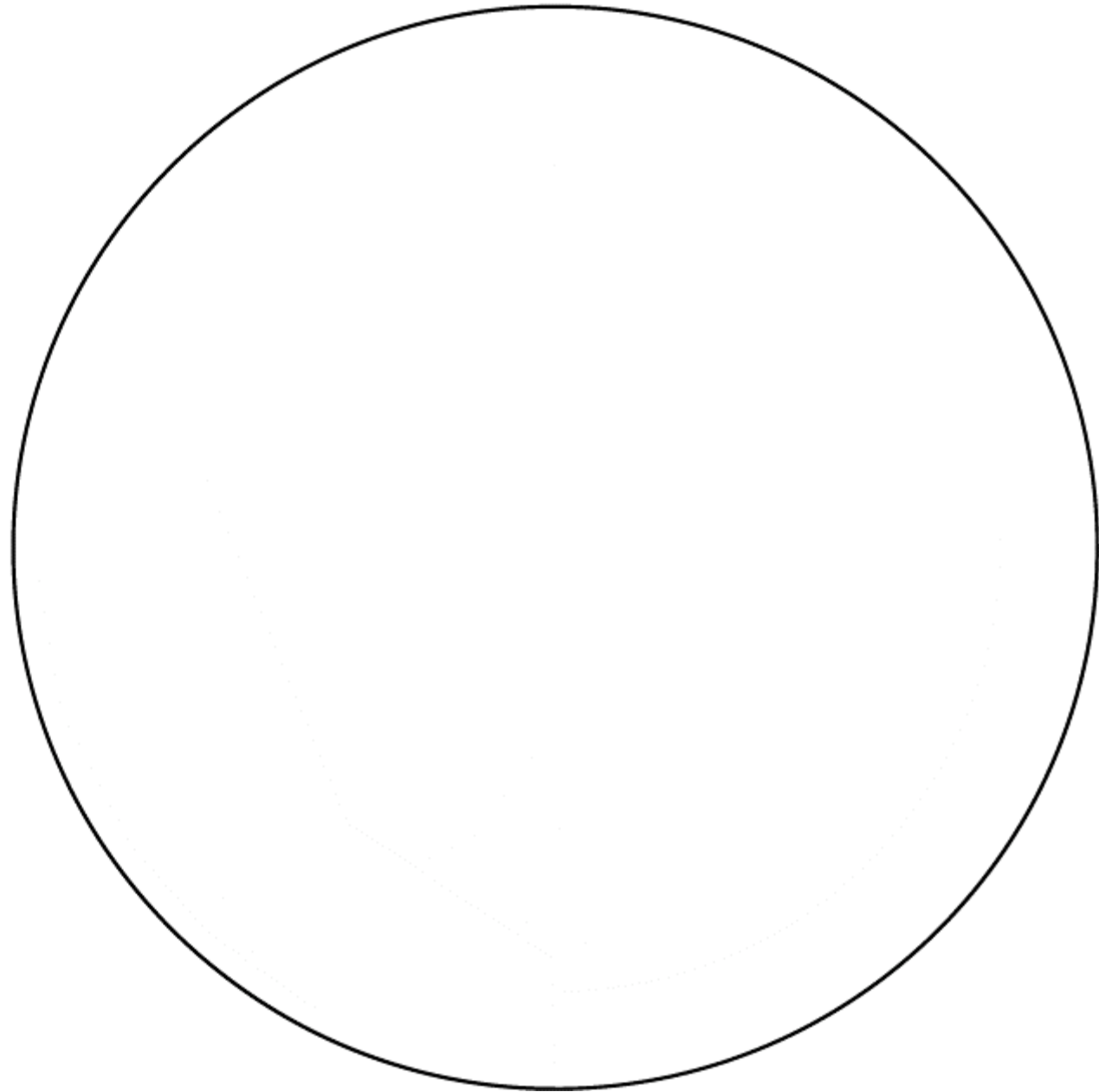




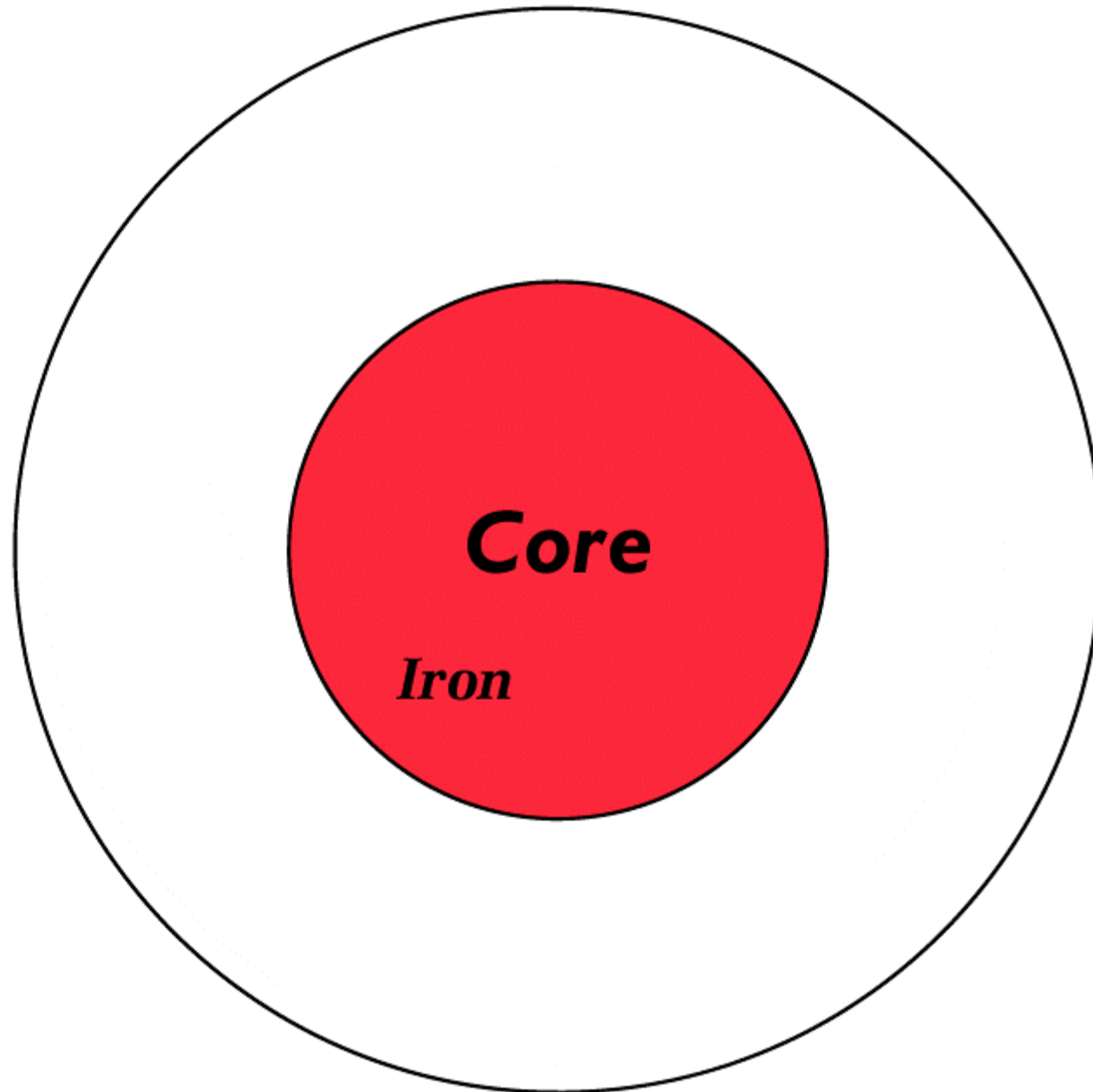
The Whole Earth and Plate Tectonics

We need to understand
what goes on inside the
Earth.

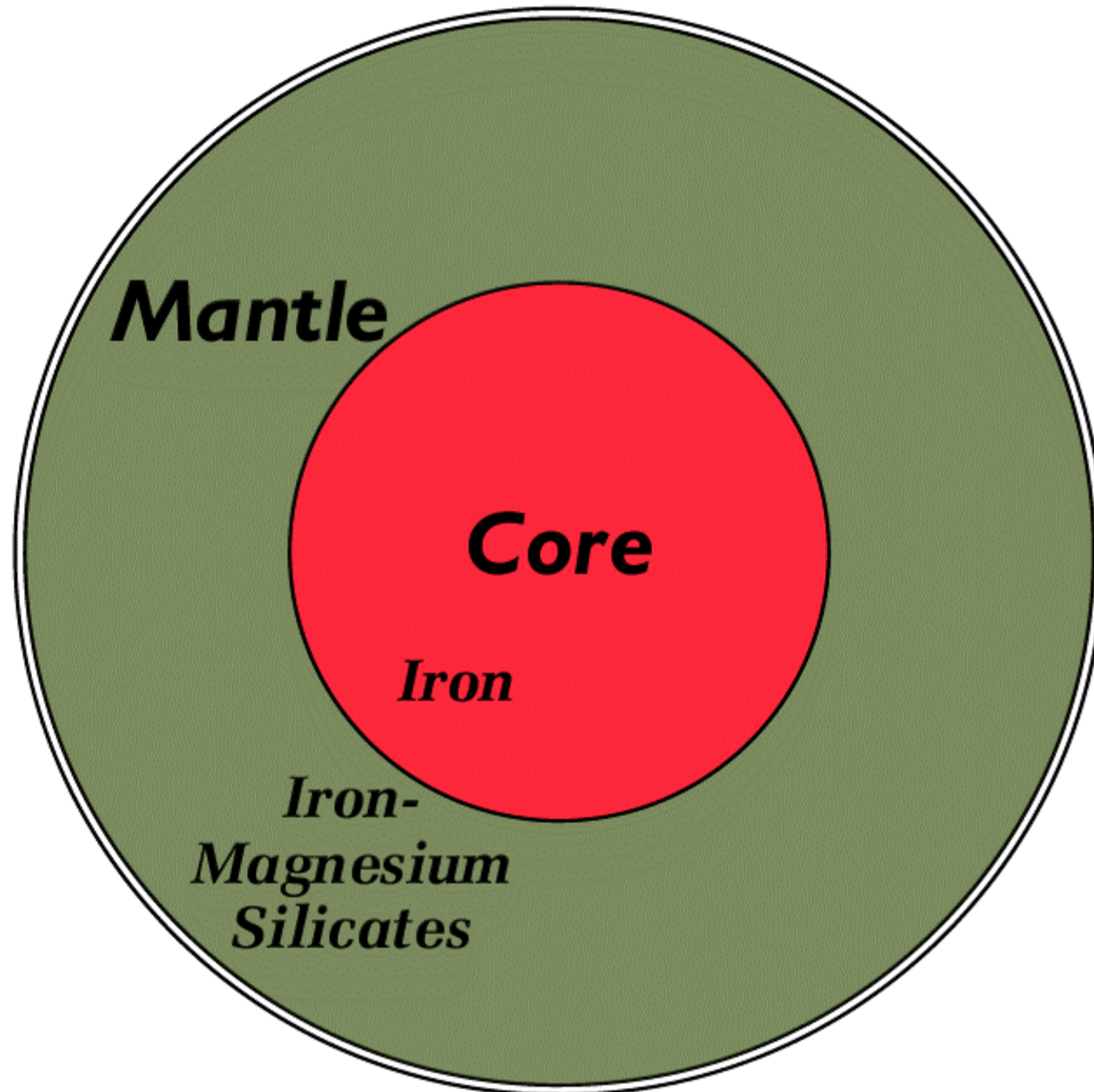
Classical Divisions of the Earth (Chemical Composition)



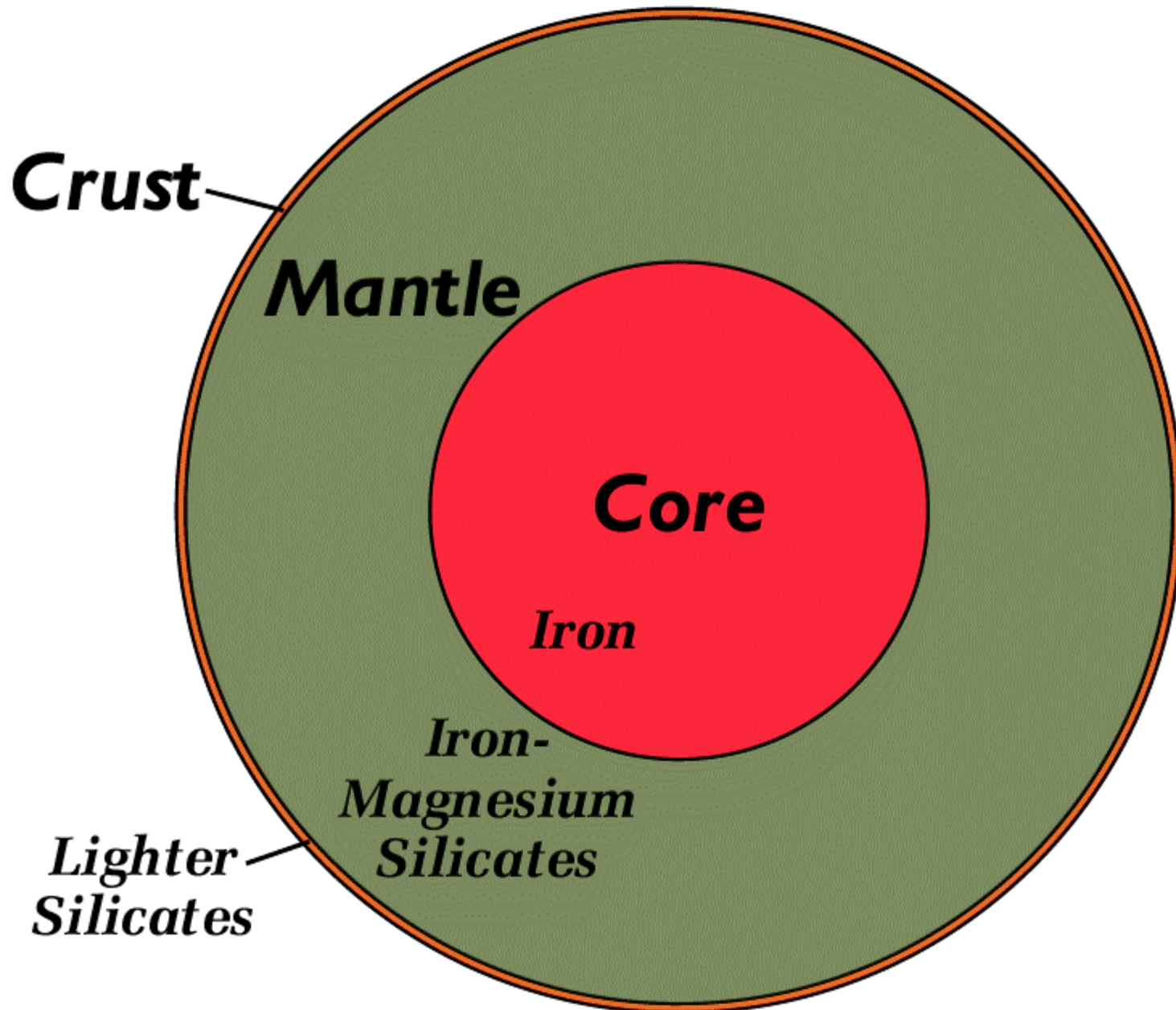
Classical Divisions of the Earth (Chemical Composition)



Classical Divisions of the Earth (Chemical Composition)



Classical Divisions of the Earth (Chemical Composition)



Classical
(Chemical Composition)

Crust

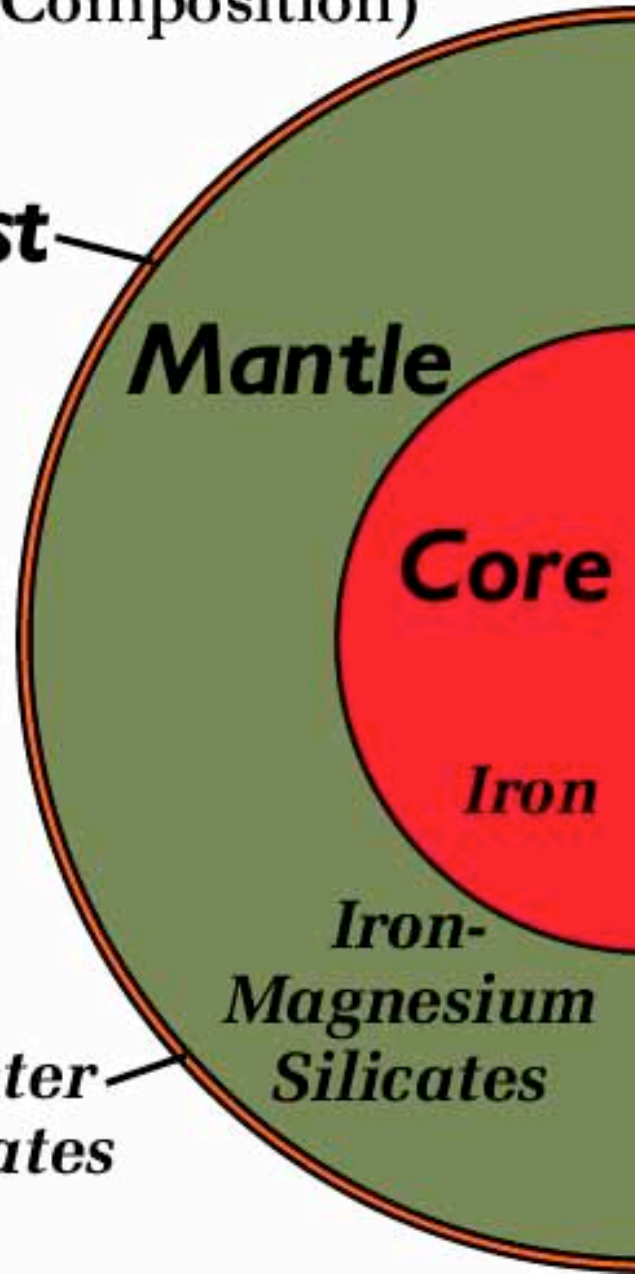
Mantle

Core

Iron

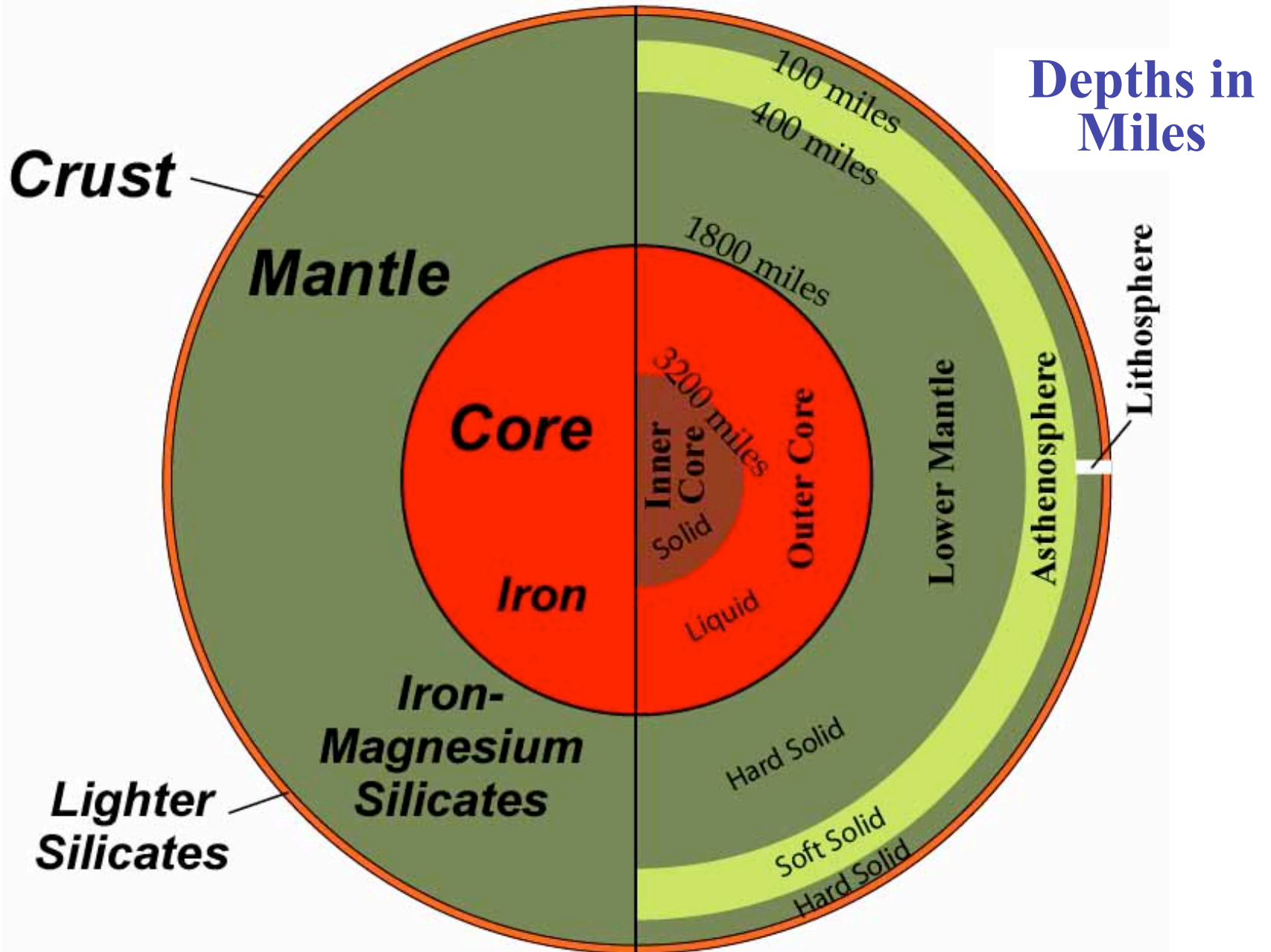
*Iron-
Magnesium
Silicates*

*Lighter
Silicates*



**Classical
(Chemical Composition)**

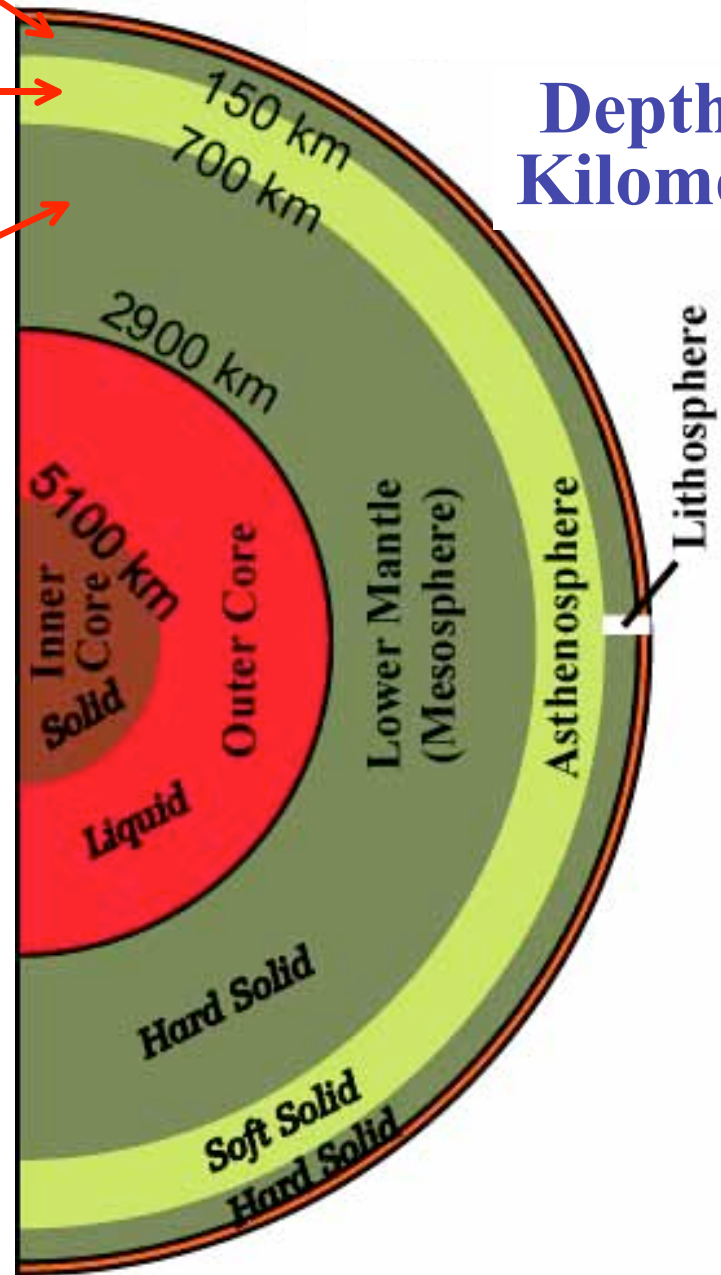
**Modern
(Physical State)**



*Oreo[®]
Cookie*



**Depths in
Kilometers**



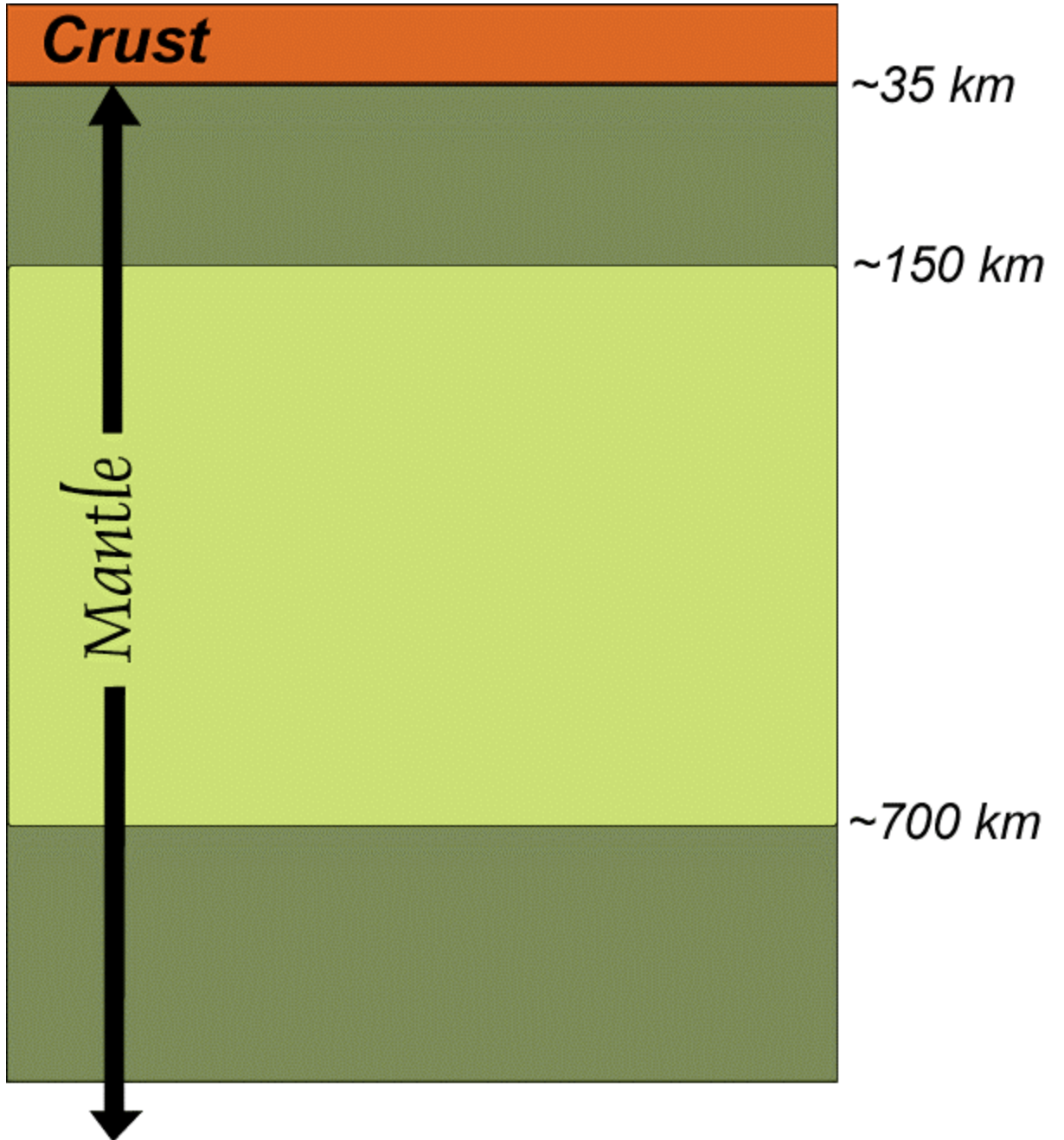
Oreo[®] Cookie



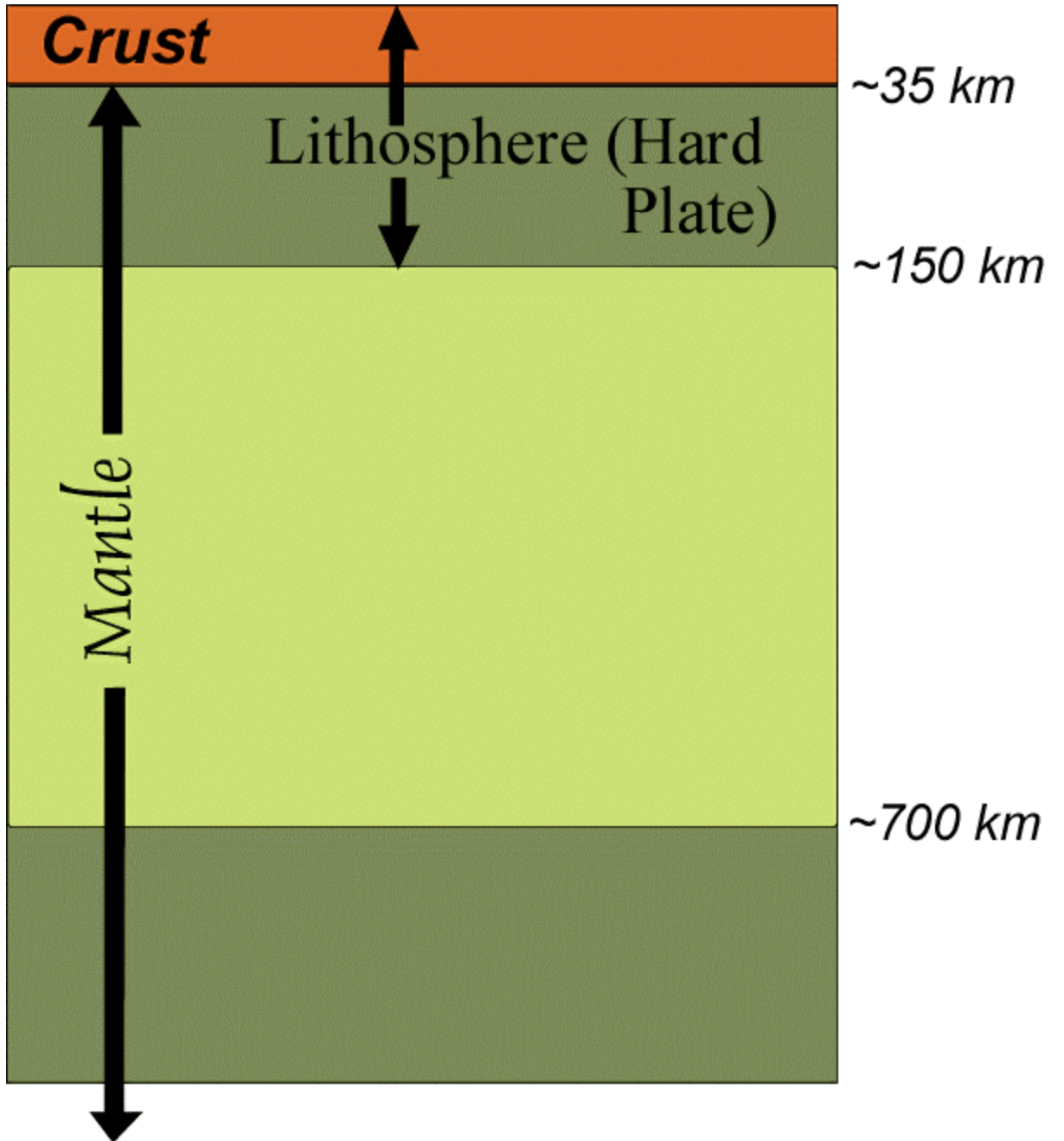
Oreo[®] Cookie



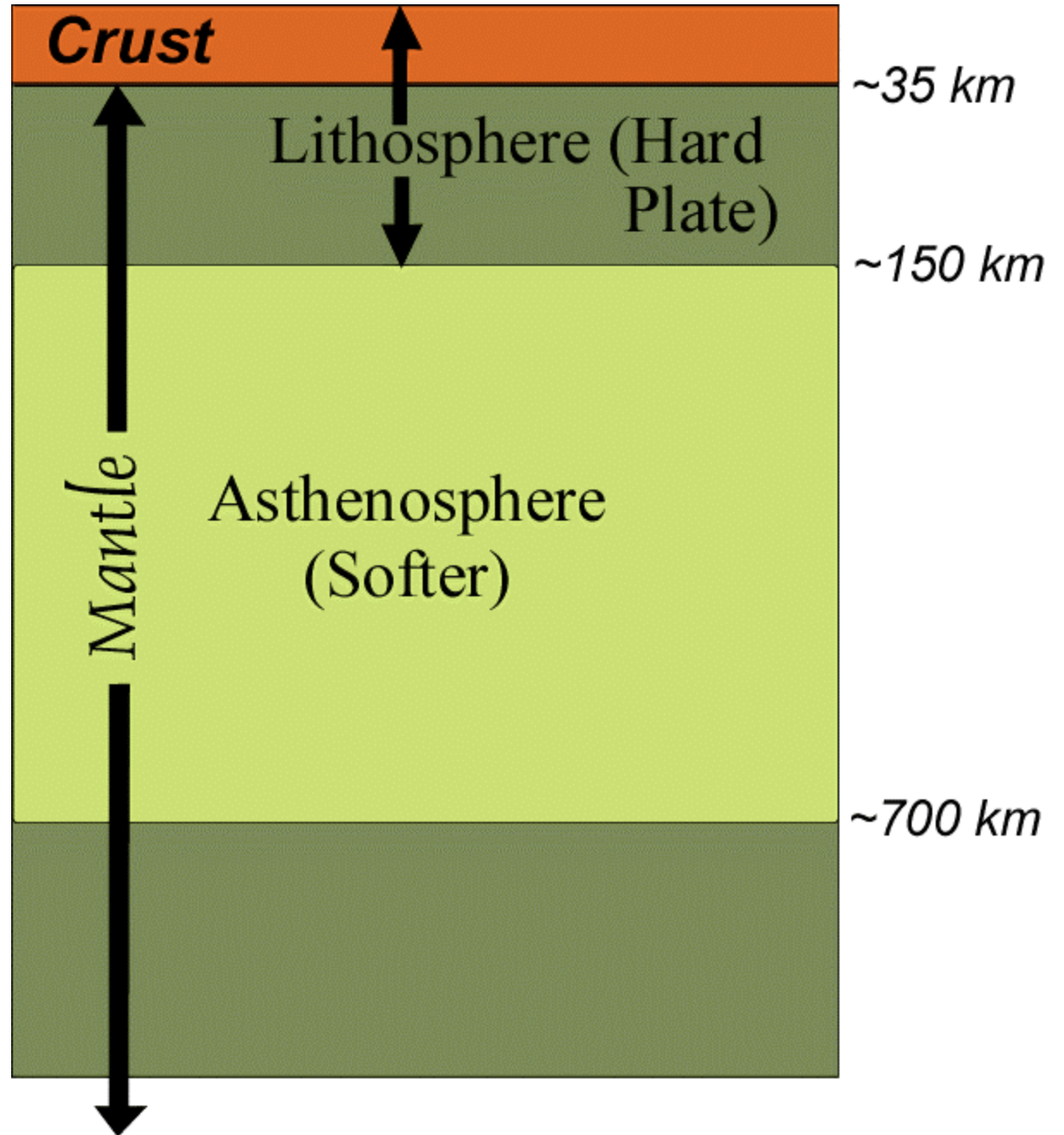
Oreo[®] Cookie



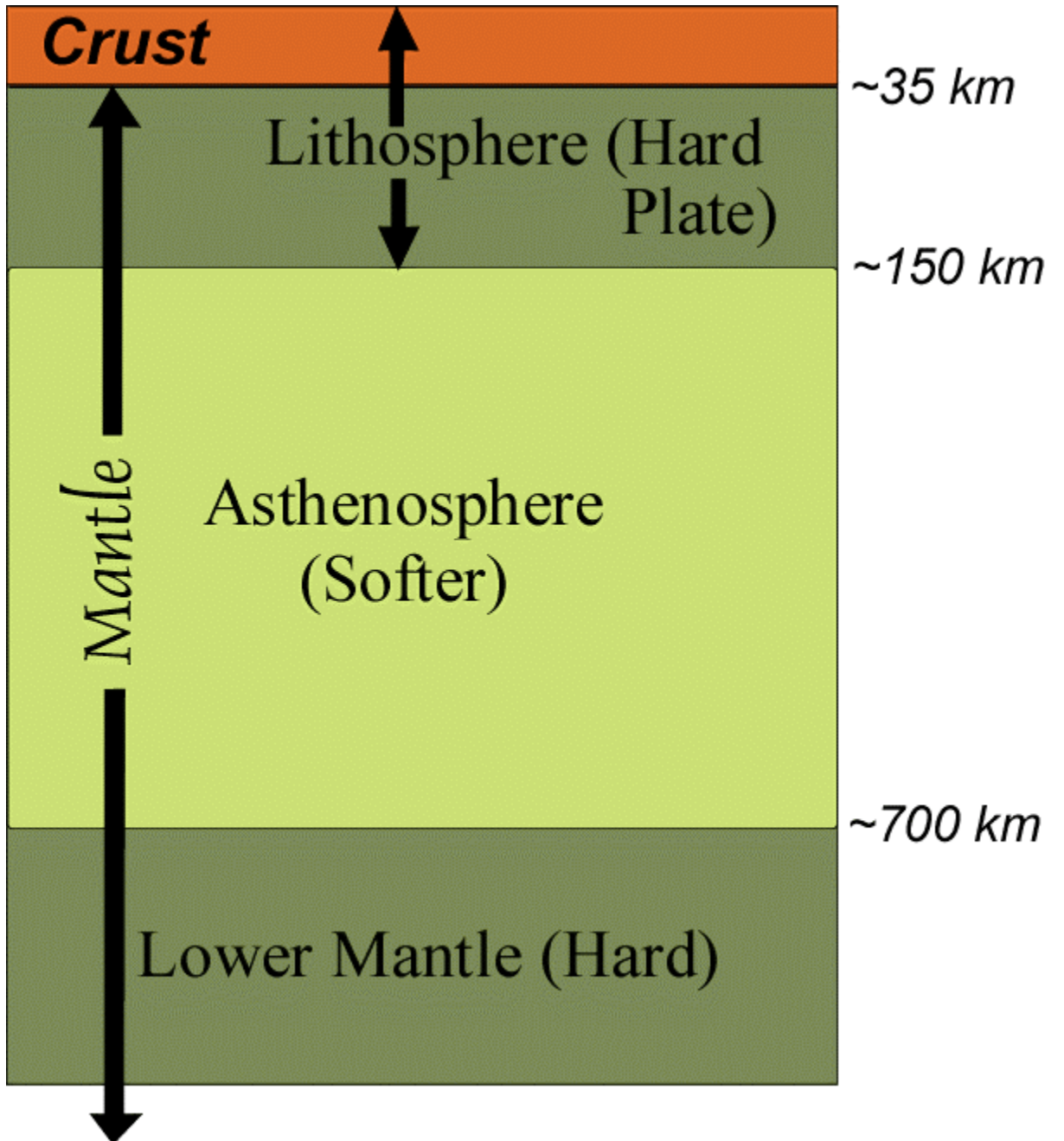
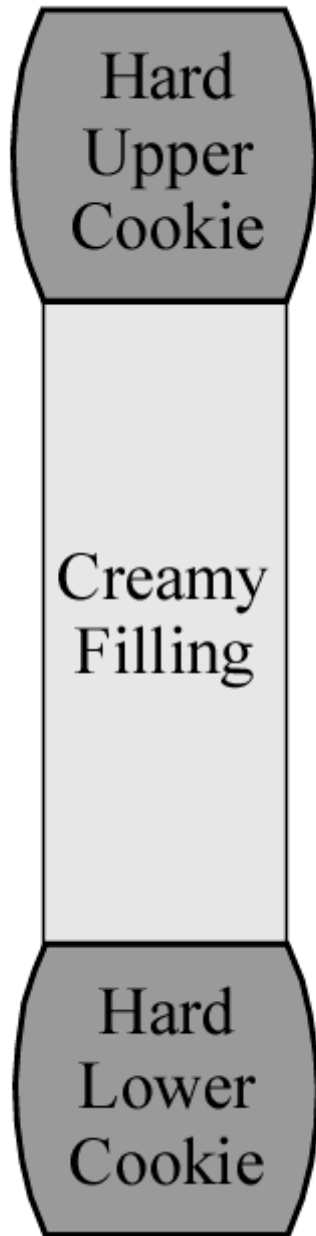
Oreo[®] Cookie



Oreo[®] Cookie



Oreo[®] Cookie





Oreo[®] Psycho-Personality Test

www.superkids.com/aweb/pages/humor/050199.sht

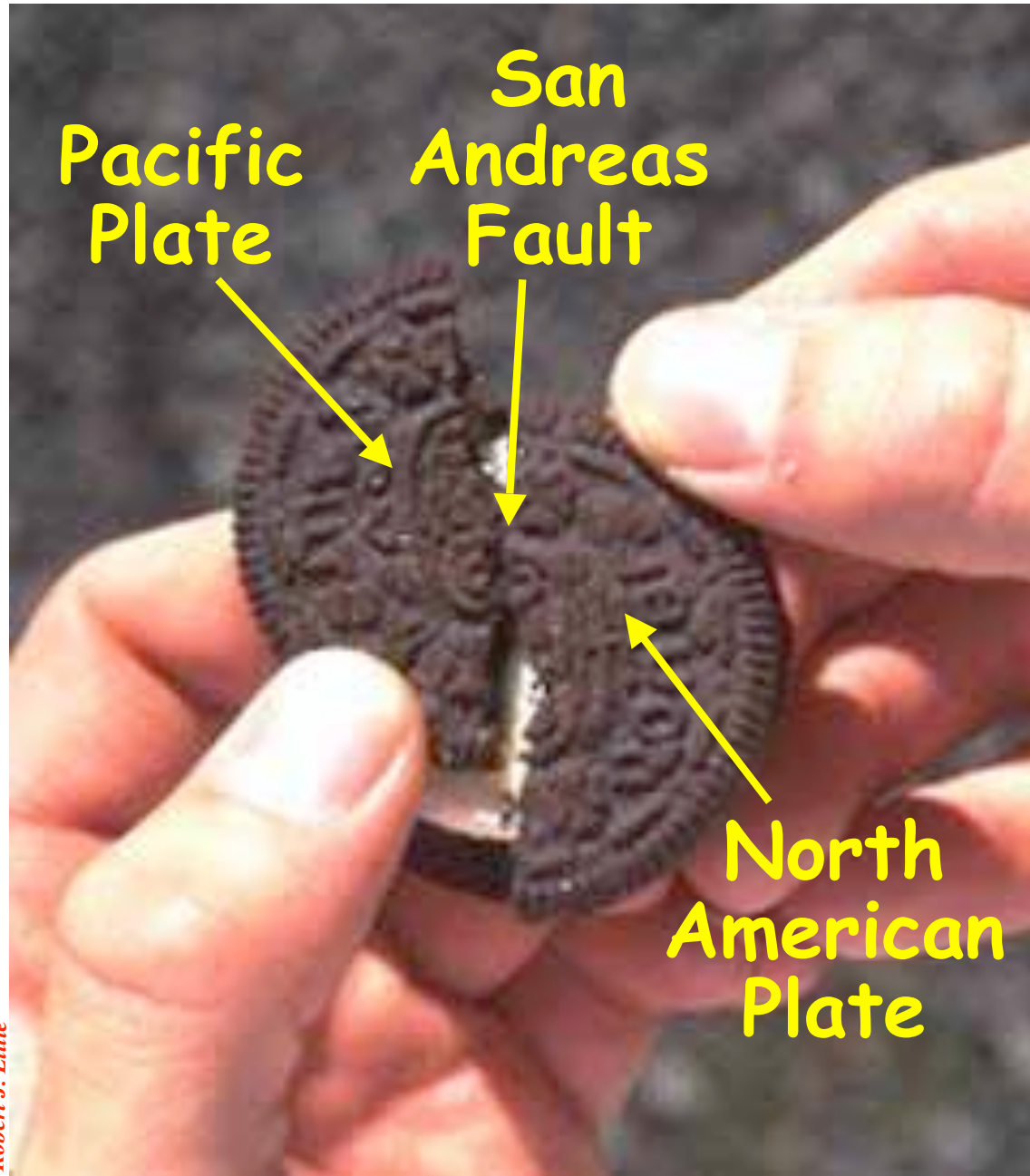
- **Psychologists have discovered that the manner in which people eat Oreo[®] cookies provides great insight into their personalities. Choose which method best describes your favorite method of eating Oreos:**
 1. The whole thing at once.
 2. One bite at a time.
 3. Slow and methodical nibbles examining the results of each bite afterwards.
 4. In little feverous nibbles.
 5. Dunked in some liquid (milk, coffee
 - 6. Twisted apart, the inside, then the cookie.**
 7. Twisted apart, the inside, and toss the cookie.
 8. Just the cookie, not the inside.
 9. I just like to lick them, not eat them.
 10. I don't have a favorite way because I don't like Oreos.

6. Twisted apart, the inside, then the cookie.

- You have a highly curious nature.**
- You take pleasure in breaking things apart to find out how they work, though you're not always able to put them back together, so you destroy all the evidence of your activities.**
- You deny your involvement when things go wrong.**
- You are a compulsive liar and exhibit deviant, if not criminal, behavior.**

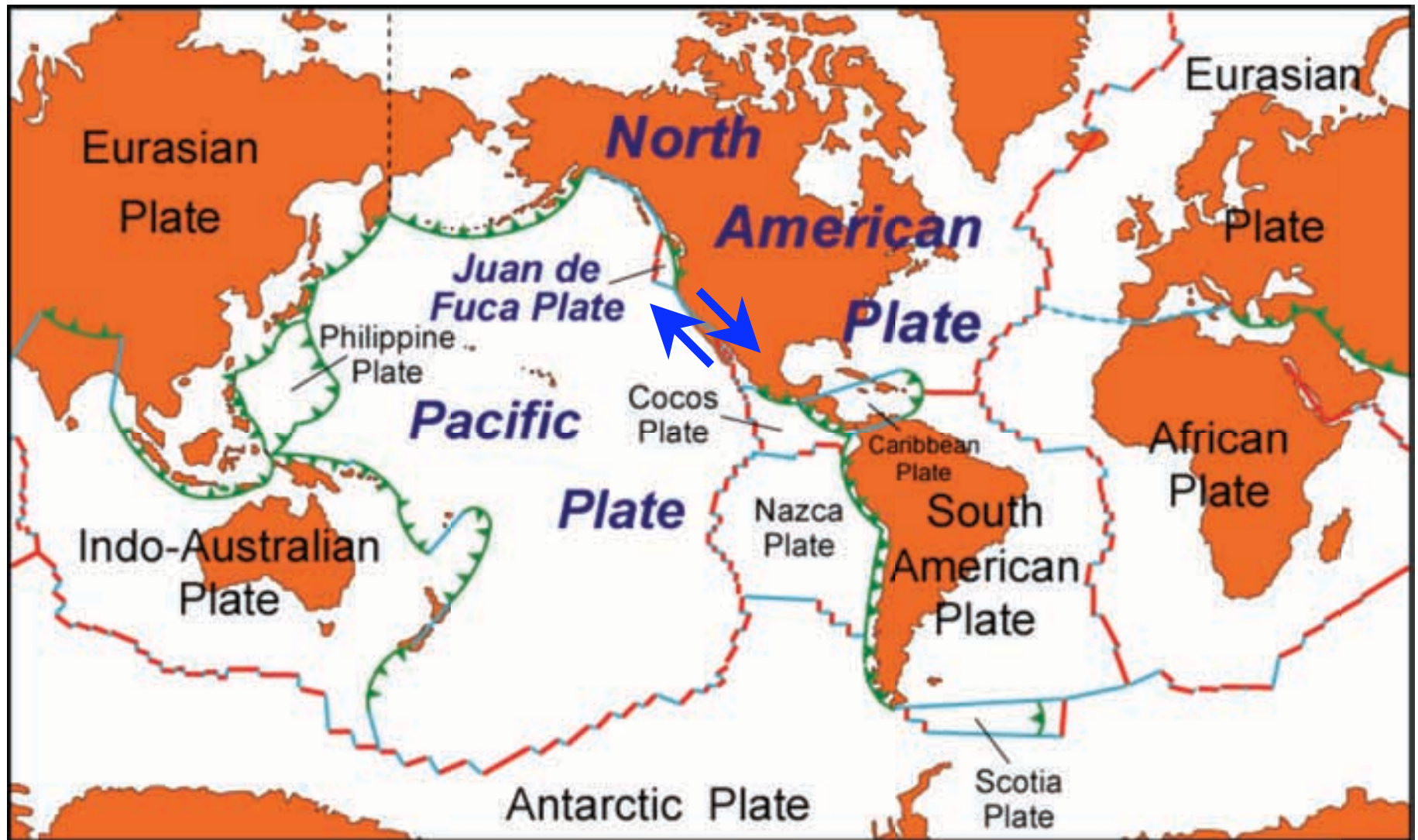
Sliding Plate over Asthenosphere





Transform Plate Boundary

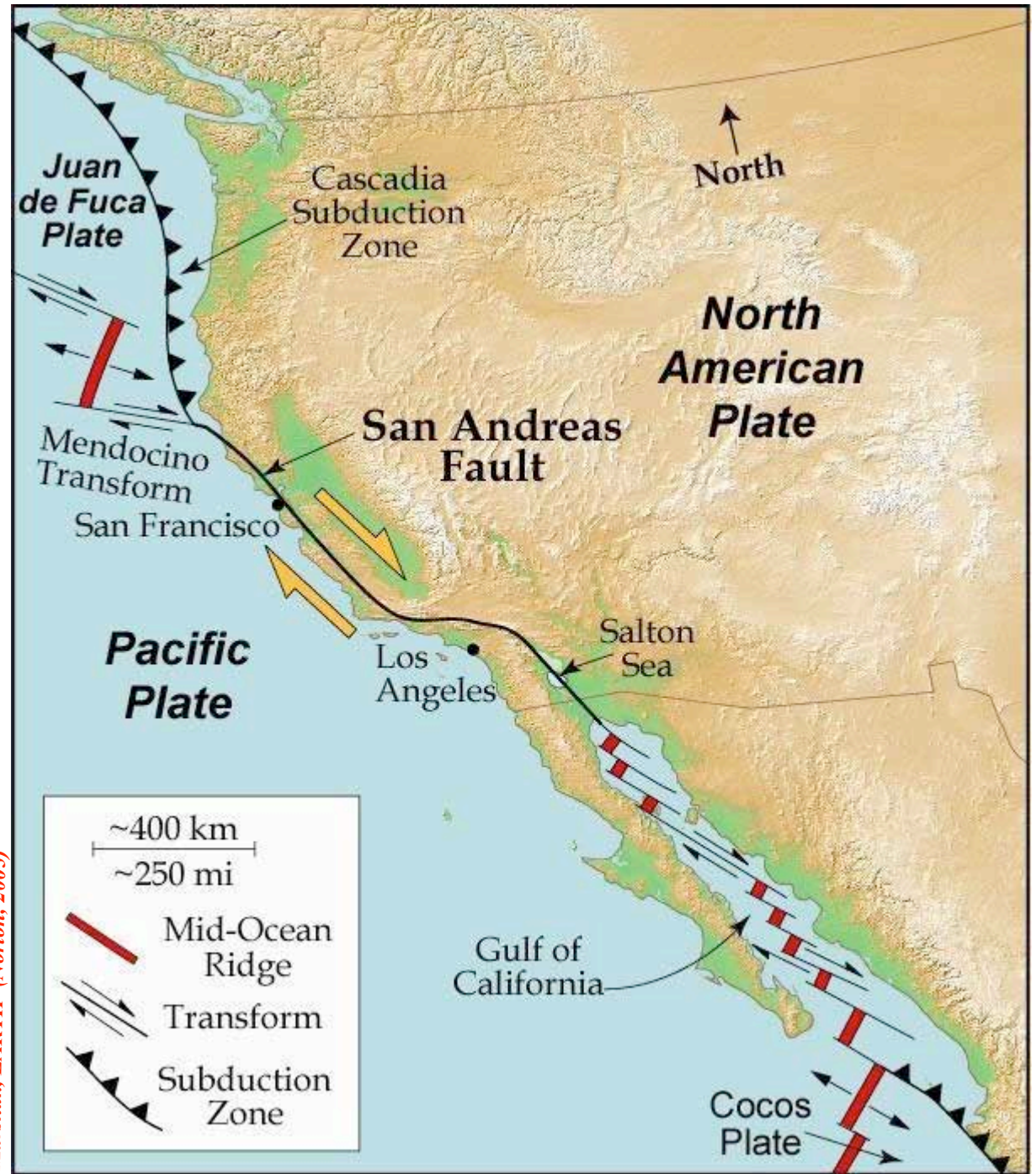
Transform Plate Boundary



San Andreas Fault

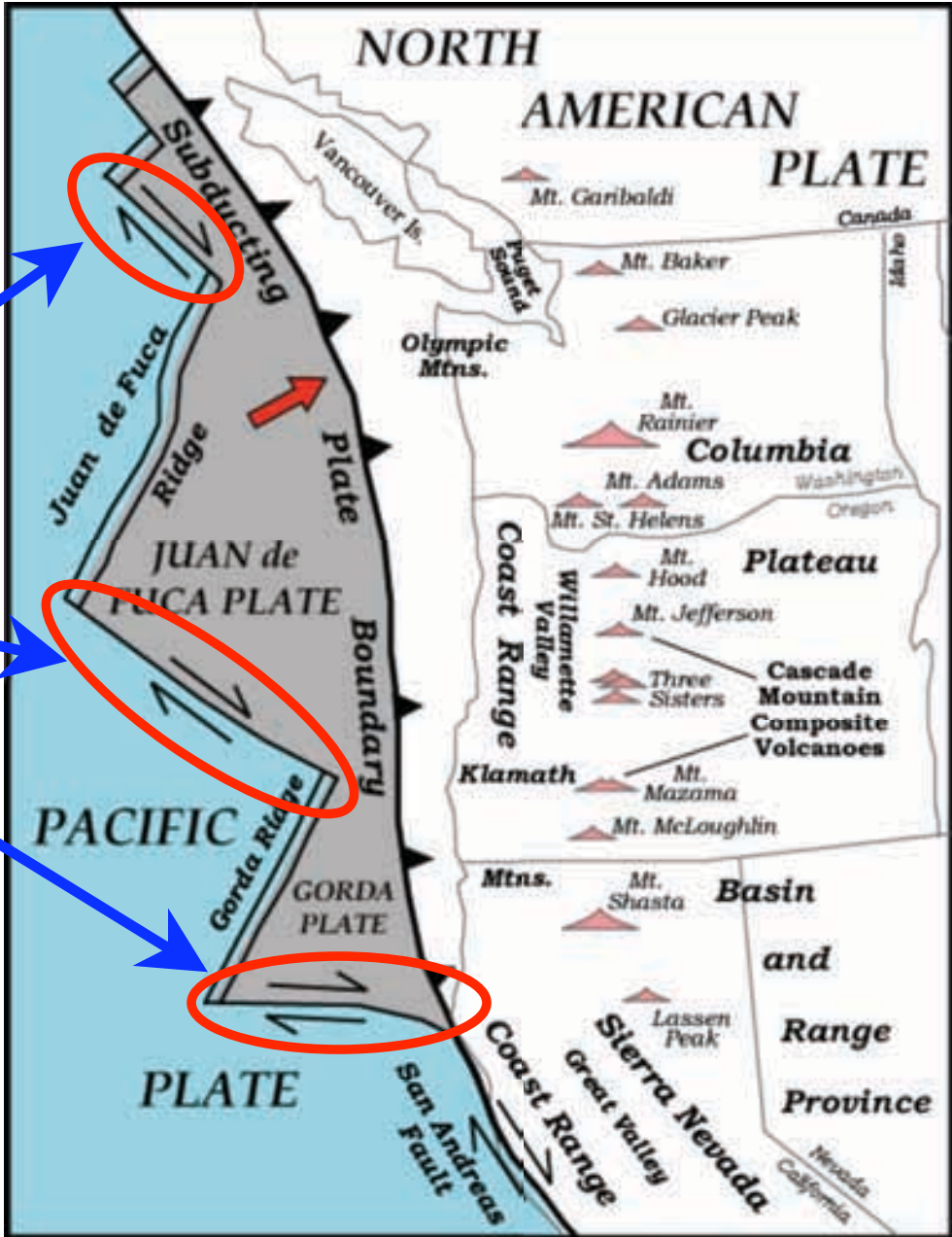
Transform Plate Boundary

*The Pacific Plate
slides past the North
American Plate
along the San
Andreas Fault in
California.*



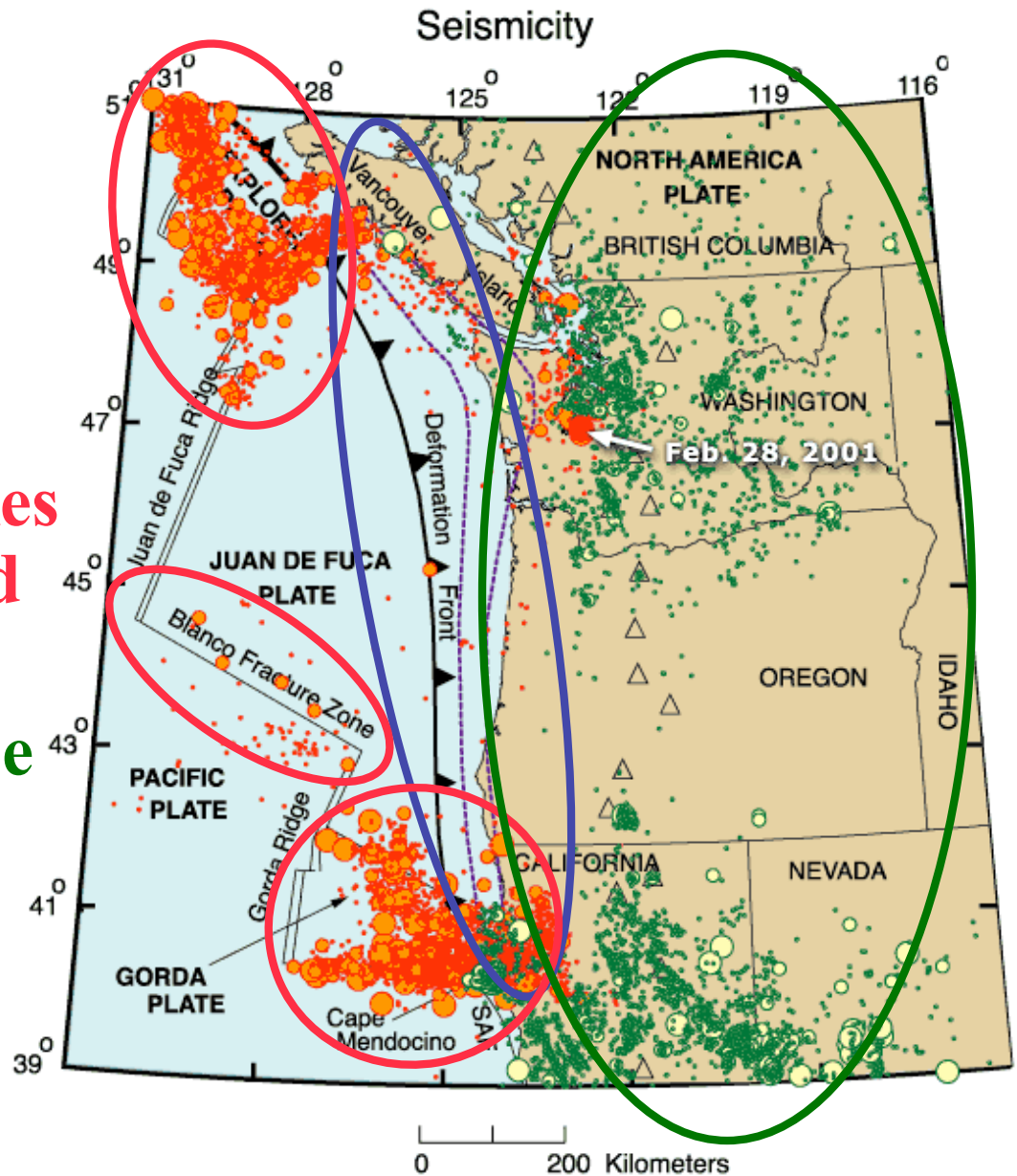
Marshak, EARTH (Norton, 2005)

*Transform
Plate
Boundaries*



Earthquakes in the Pacific Northwest

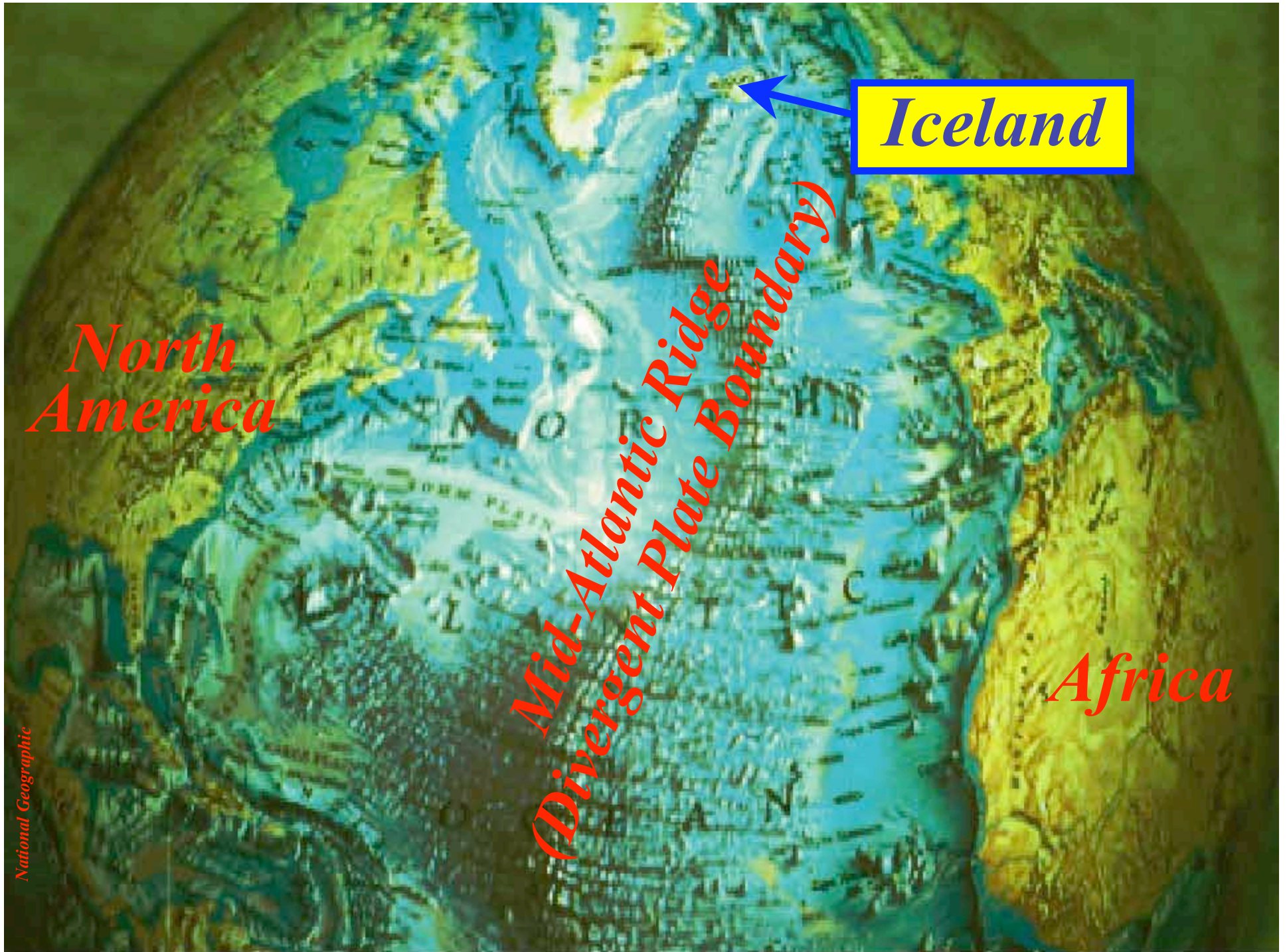
- Where are the big earthquakes along the Cascadia Subduction Zone?
- What about earthquakes between the Pacific and Juan de Fuca Plates?
- And earthquakes on the overriding North American Plate?





Robert J. Lillie

Divergent Plate Boundary



Iceland

North America

Africa

*Mid-Atlantic Ridge
(Divergent Plate Boundary)*

Iceland



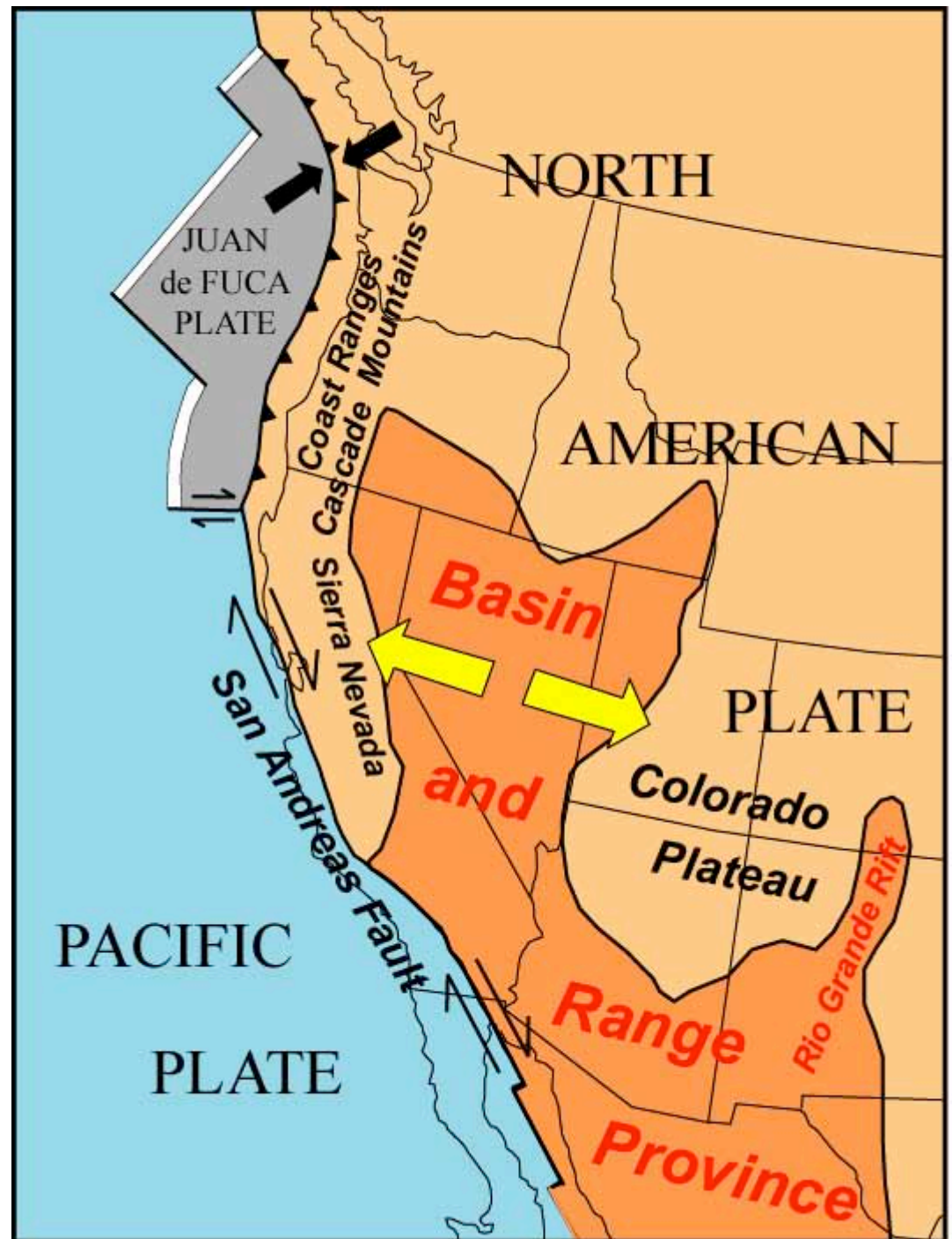


Iceland

Divergent Plate Boundary

The Basin and Range Province

is a Continental Rift Zone, the early stages of plate divergence





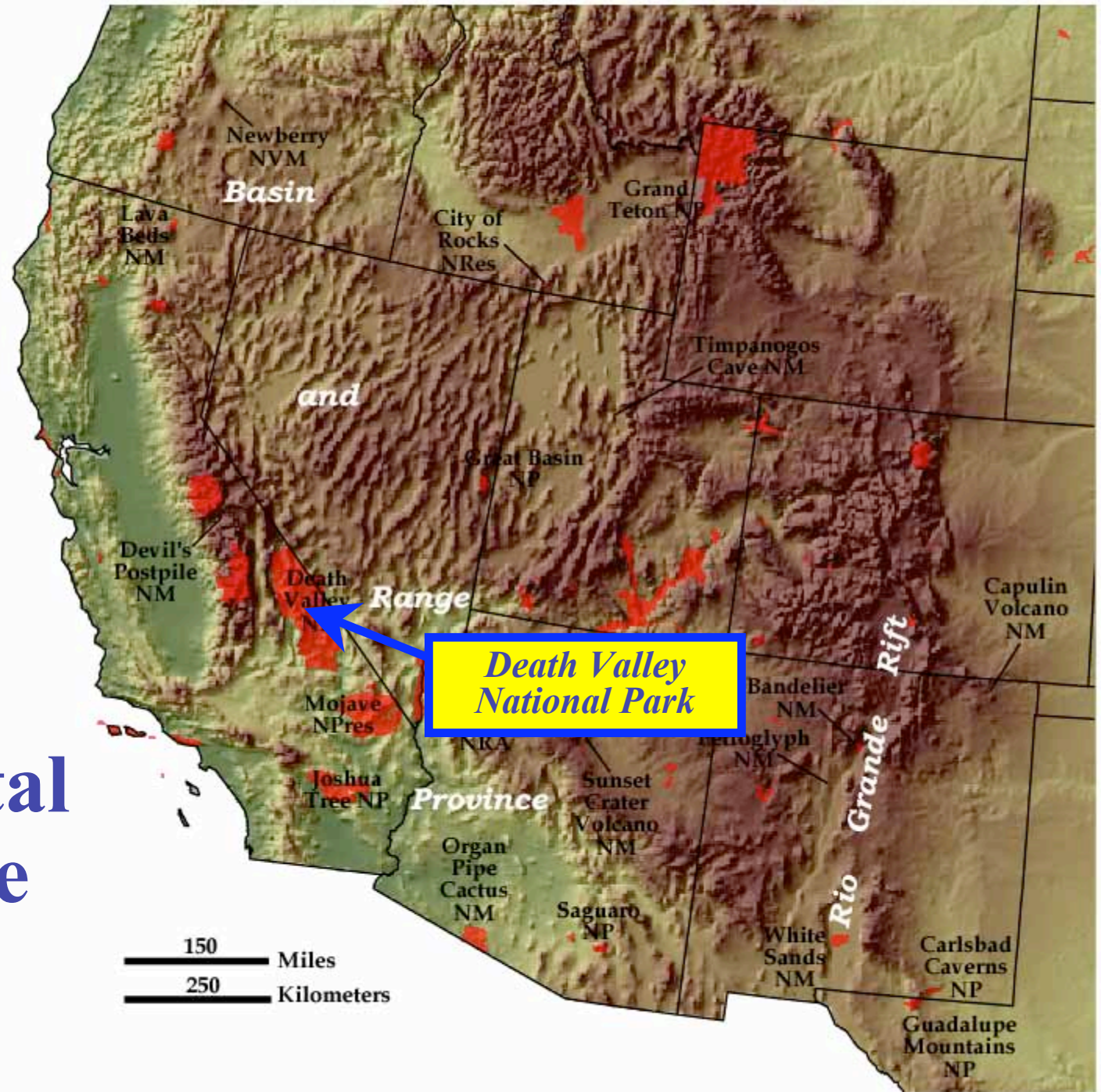
Robert J. Lillie

Plates Pulling Apart--Continental Rift Zone

National Park Lands



Active Continental Rift Zone

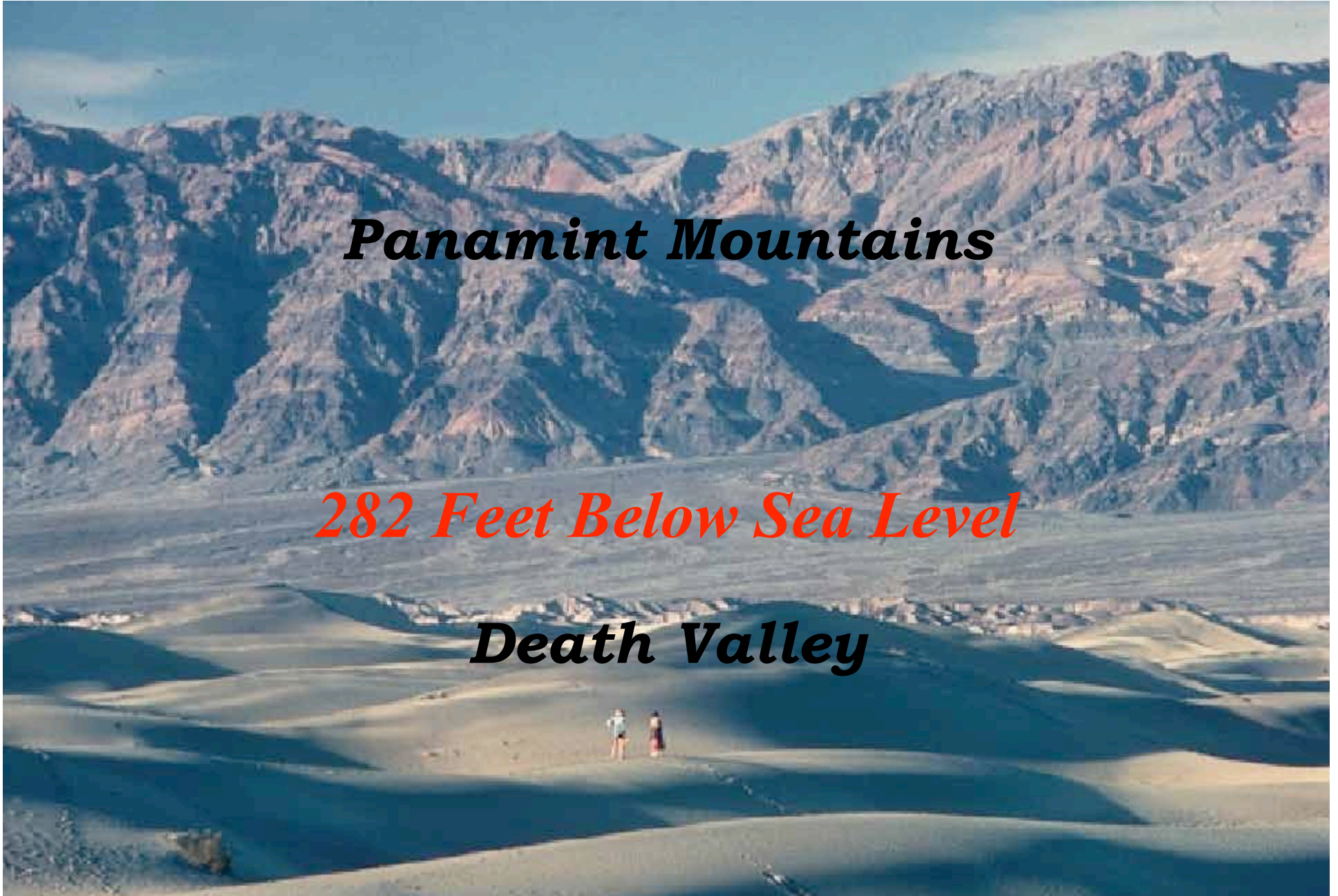


Death Valley National Park, California

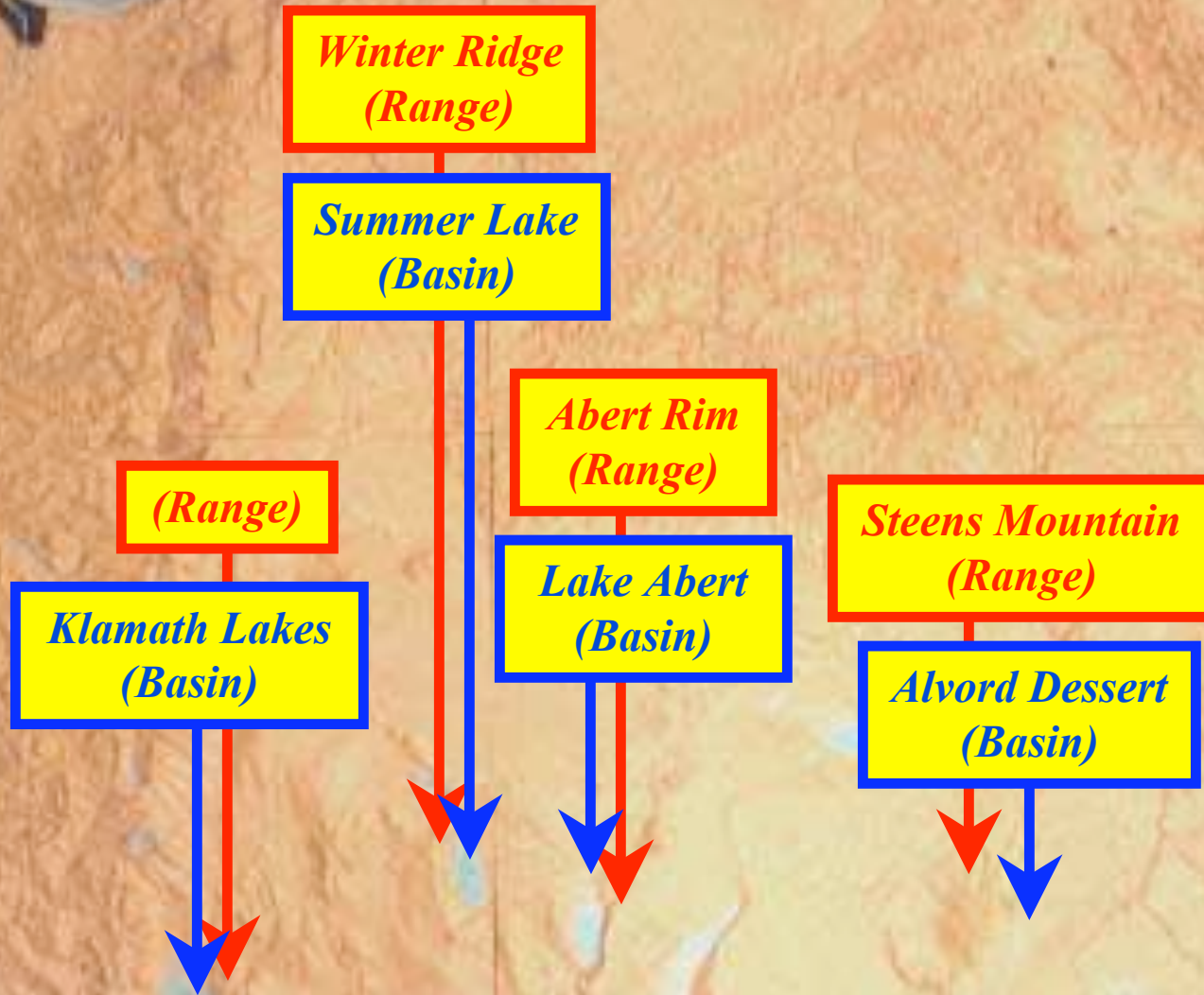
Panamint Mountains

282 Feet Below Sea Level

Death Valley



Basin and Range Province



Extension, deformation, and sedimentation in a basin-and-range Province



Typical rift features include:

- 1) Down-dropped faults and uplifted escarpments
- 2) Sediment filled valleys from erosion and streams

IRIS

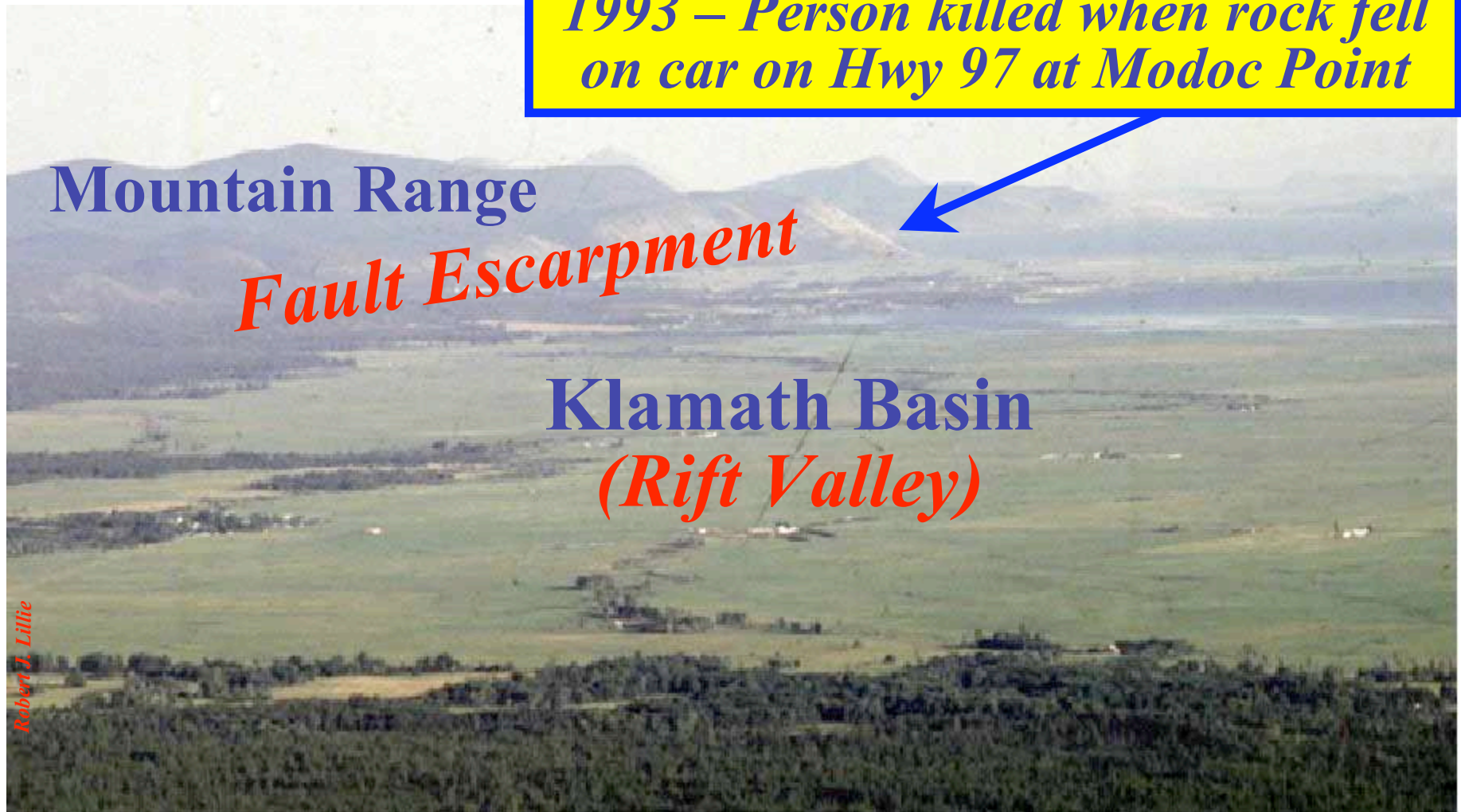
(not to scale)

earth
scope

www.iris.edu (Animation by Jenda Johnson - Time 0:31)

Klamath Basin, Oregon

*1993 – Person killed when rock fell
on car on Hwy 97 at Modoc Point*



*View looking south from
Crater Lake National Park*

*Klamath Falls Earthquake,
Sept. 20, 1993*

**Continental Rifting in the
Basin and Range Province**

**Two earthquakes (one a magnitude 5.9
and one a 6.0) struck Klamath
Falls the night of September 20, 1993,
damaging more than 1000
structures and claiming two lives.**



Basin and Range earthquakes

Zoom in
to a cross section
of this area
to watch
an earthquake

Fault

AMPLITUDE
digitizer counts

Seismogram

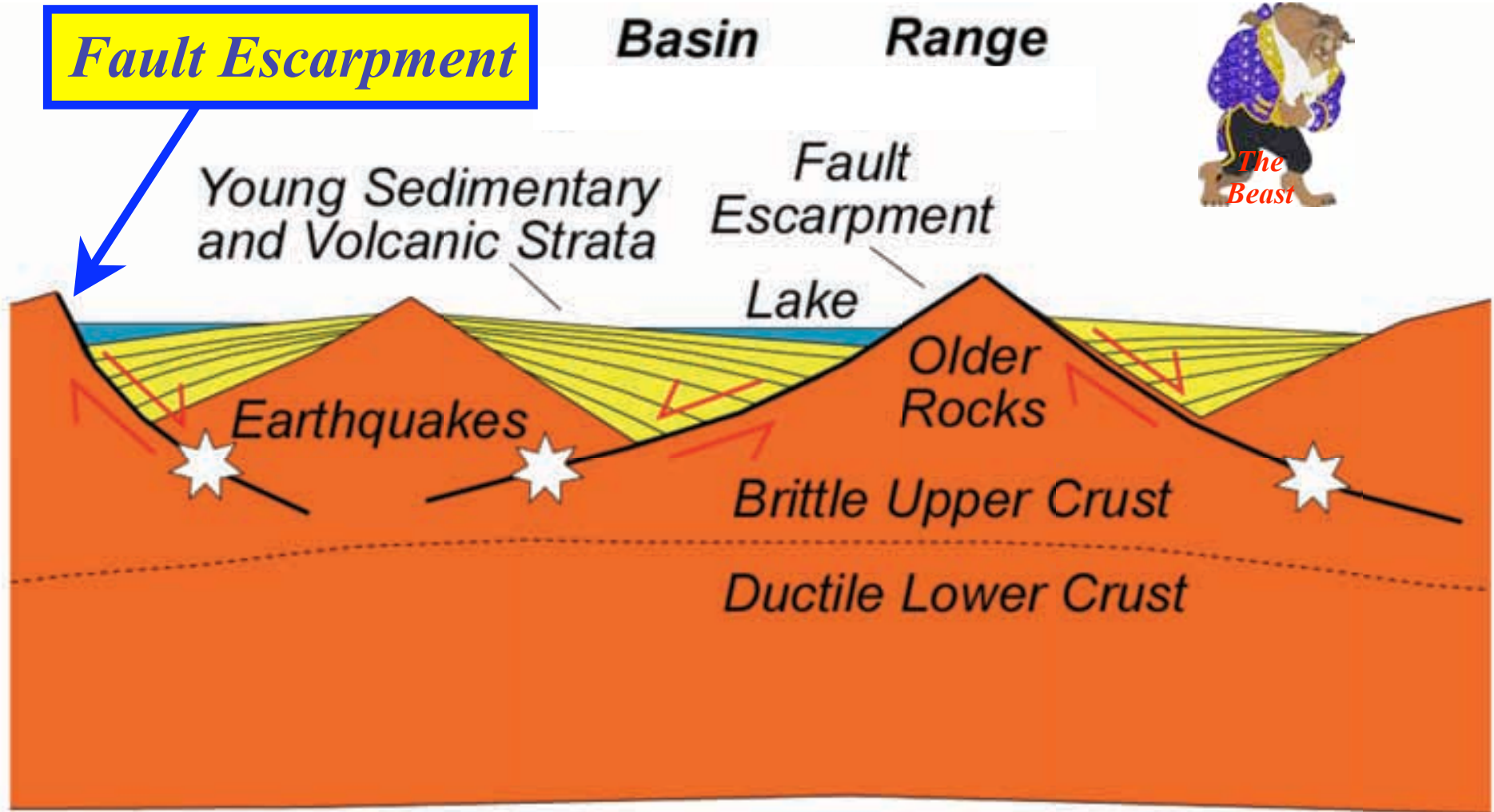
0 1 2 3 4 5 6 7 8 seconds

IRIS

earth
scope

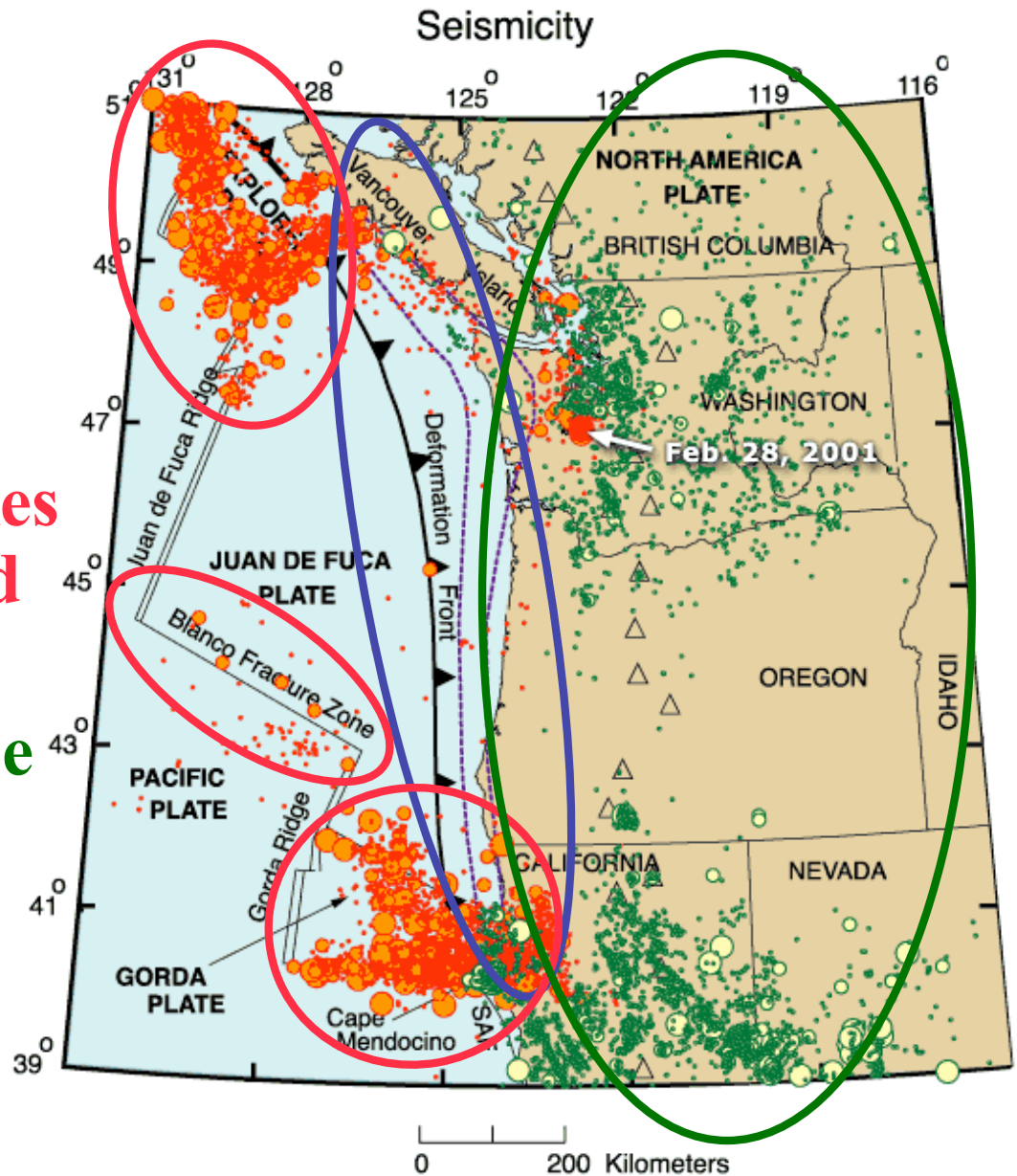
www.iris.edu (Animation by Jenda Johnson - Time 0:18)

Earthquakes in a Continental Rift Zone



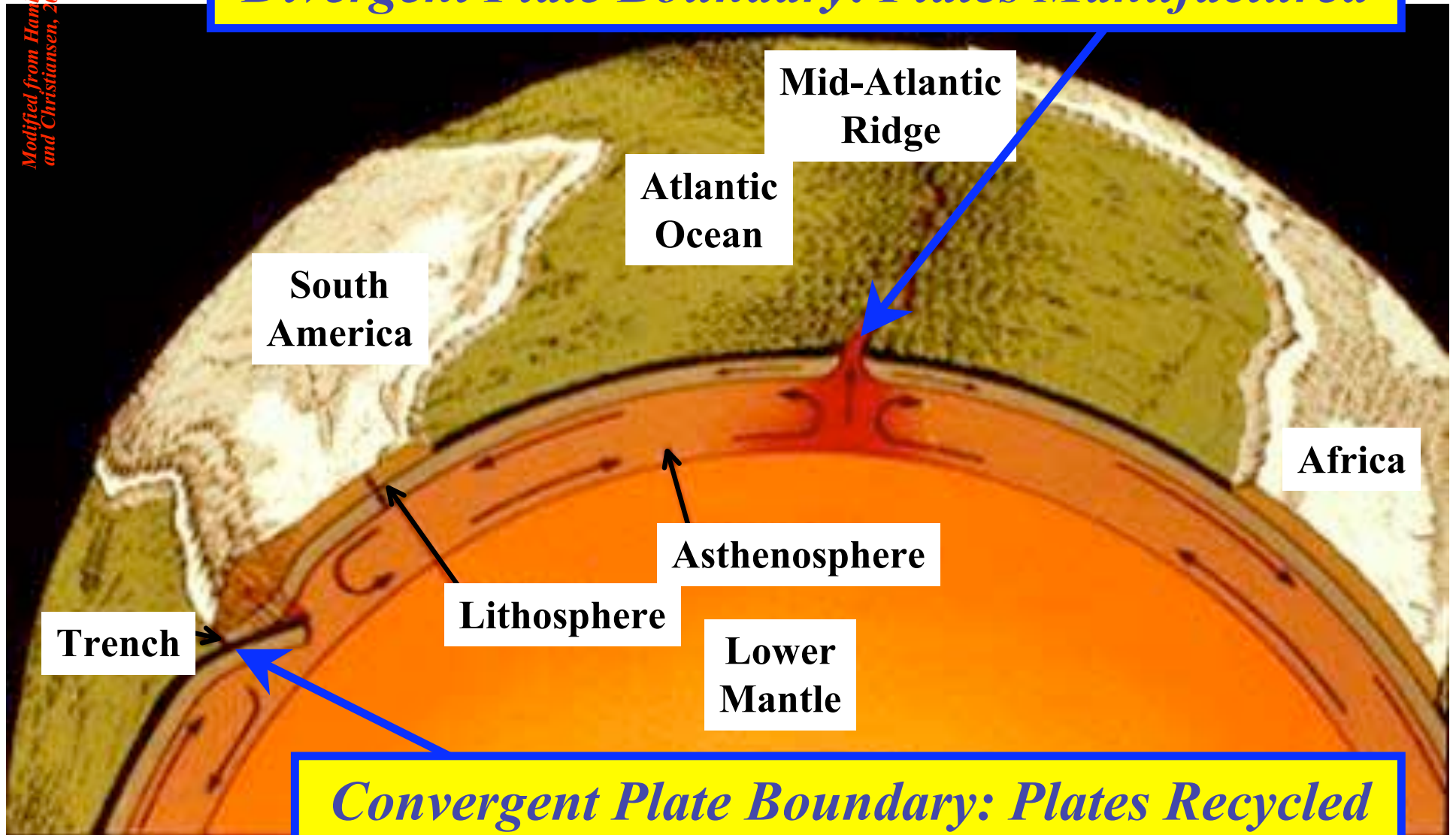
Earthquakes in the Pacific Northwest

- Where are the big earthquakes along the Cascadia Subduction Zone?
- What about earthquakes between the Pacific and Juan de Fuca Plates?
- And earthquakes on the overriding North American Plate?



Giant Re-Cycling Machine!! 😊

Divergent Plate Boundary: Plates Manufactured



Modified from Hamblin and Christiansen, 2001

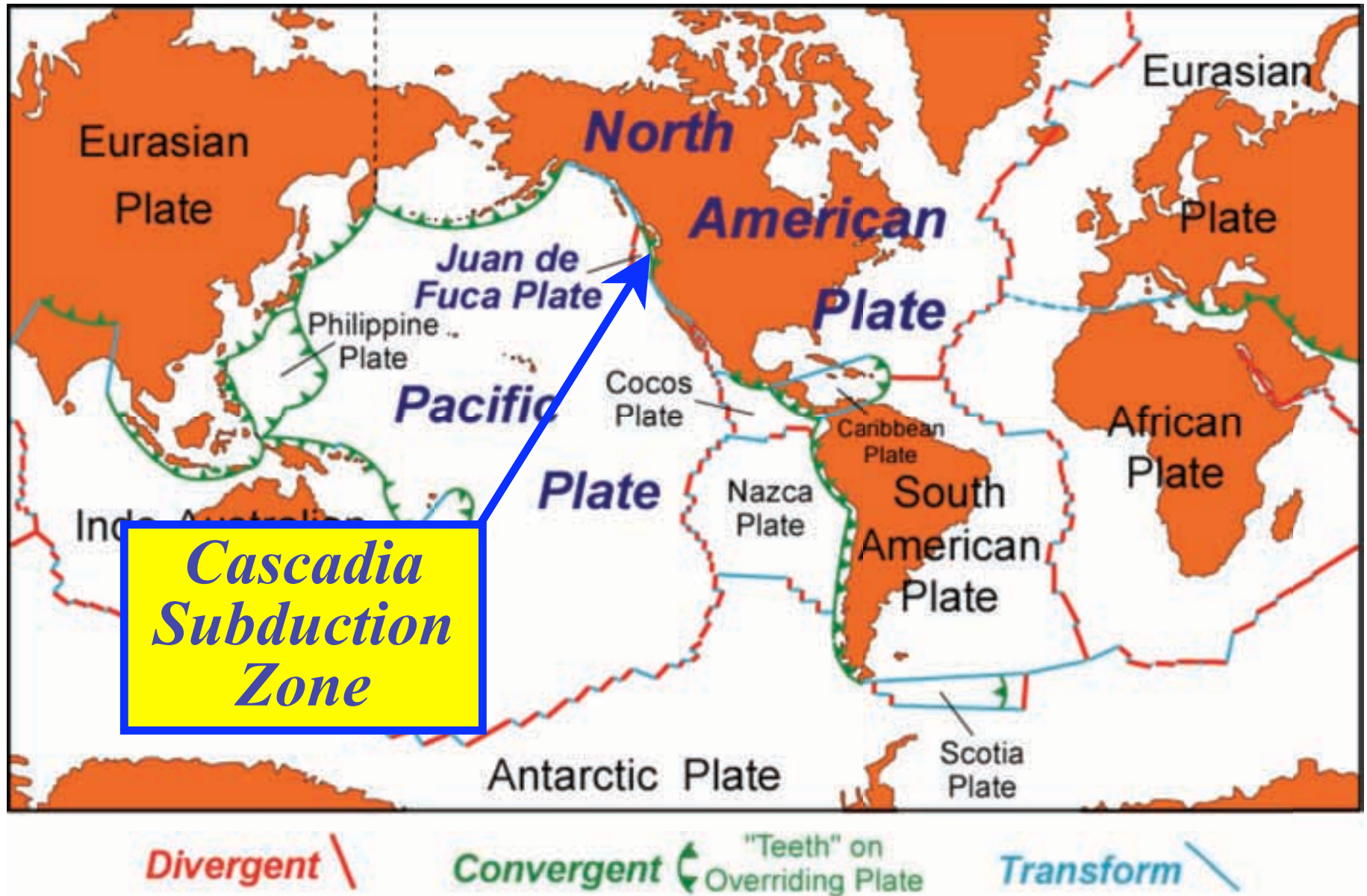
Andes Mountains, South America



Osorno volcano near Puerto Montt, Chile

<http://whatonearth.olehnielsen.dk/volcanoes.asp>

Subduction Zones rim the Pacific Ocean



*Cascadia
Subduction
Zone*



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Parks and Plates
©2005 Robert J. Lillie

Plate Tectonics--Subduction Zone

Oregon

Cascadia

Coast Range

Willamette Valley

Cascade Volcanoes

Subduction

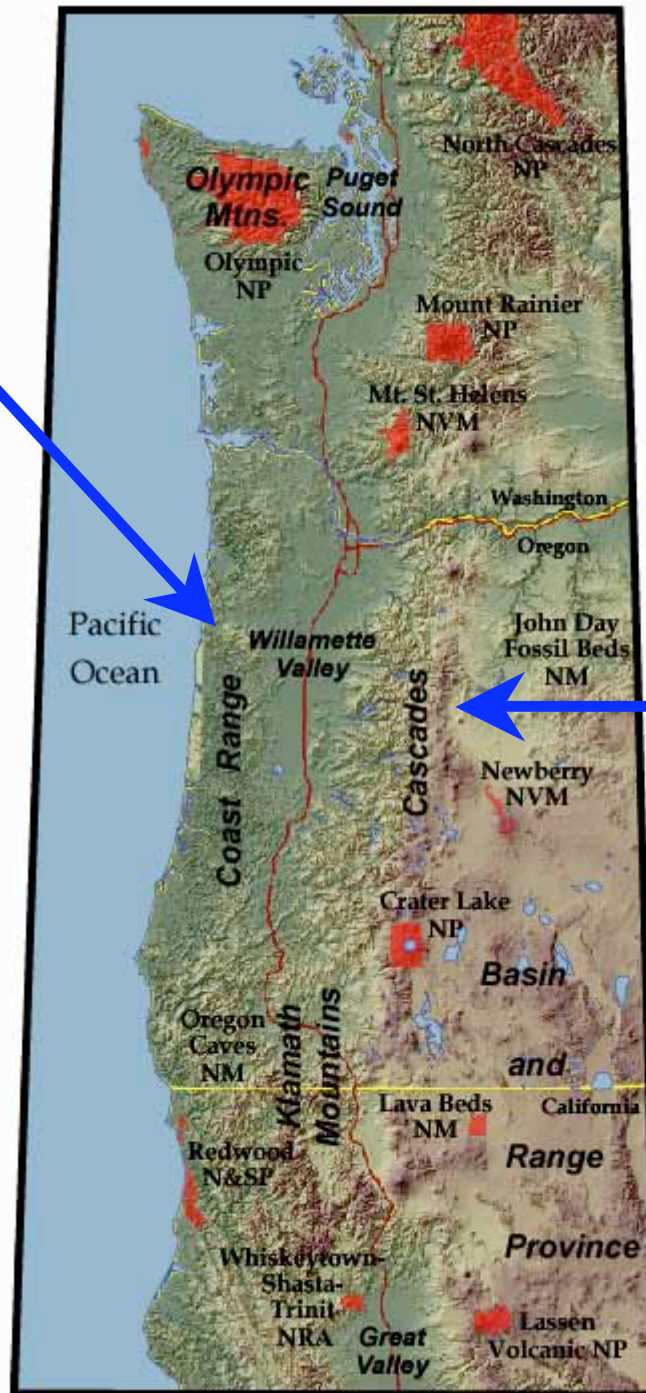
Zone



Coastal Ranges

1. Why are there two parallel mountain ranges in the Pacific Northwest?

2. Why are there earthquakes, tsunamis and volcanic eruptions?

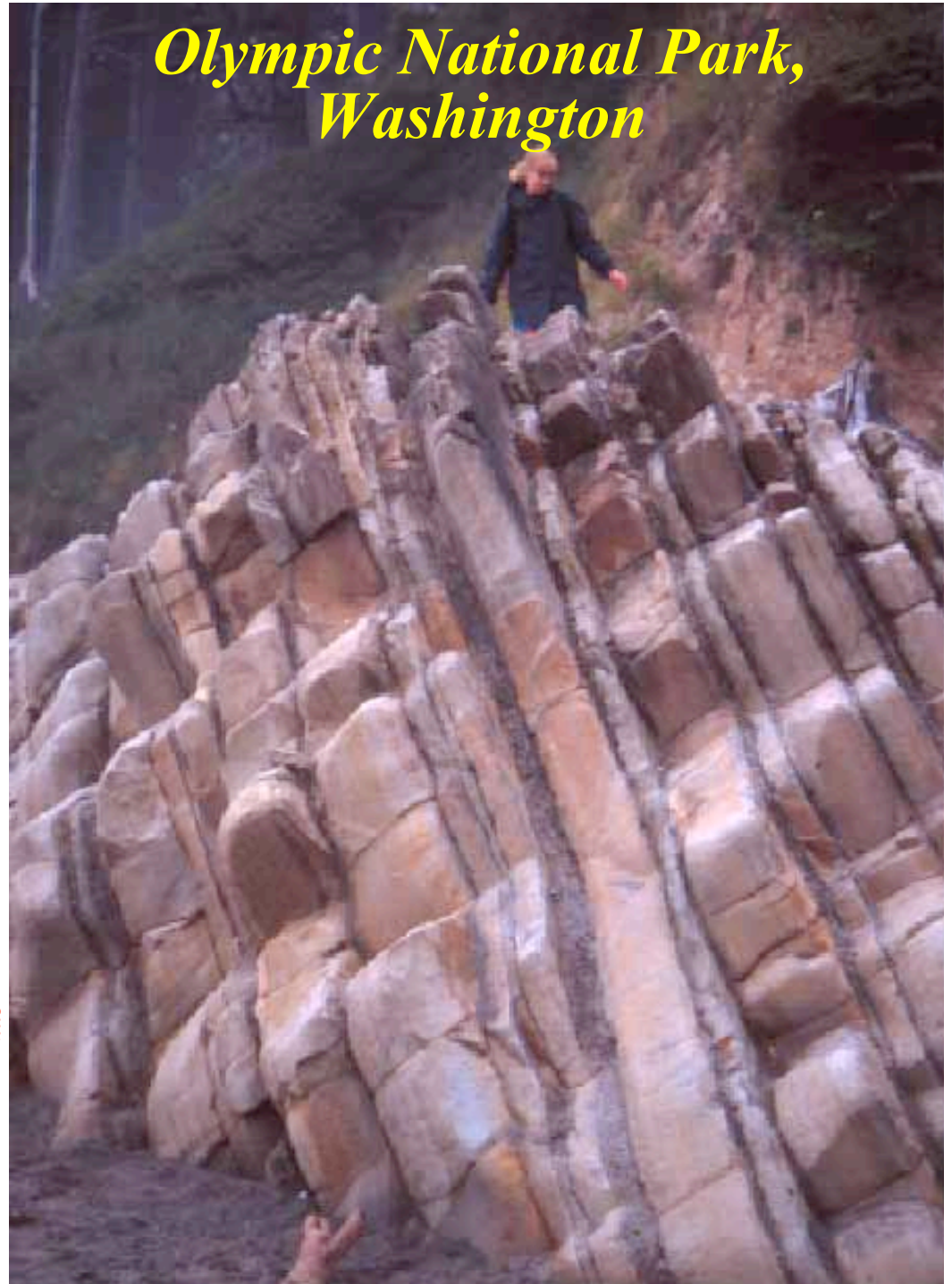


Cascade Volcanoes

**National Park
Lands in the
Pacific Northwest**

Coastal Ranges

*Layers Lifted out of
the Sea*



Cascade Mountains



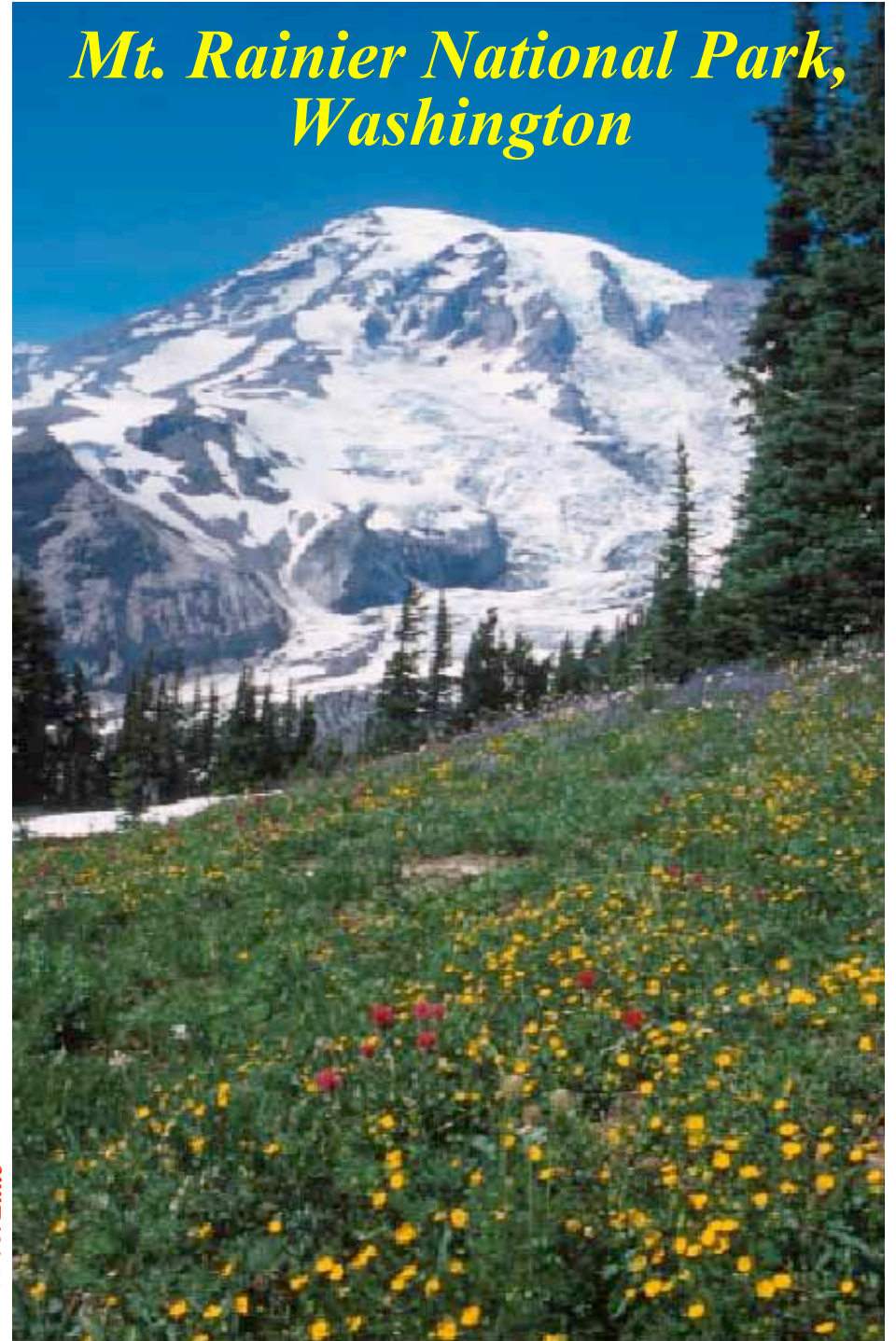
Beauty

*Steep, Explosive
Volcanoes*



*The
Beast*

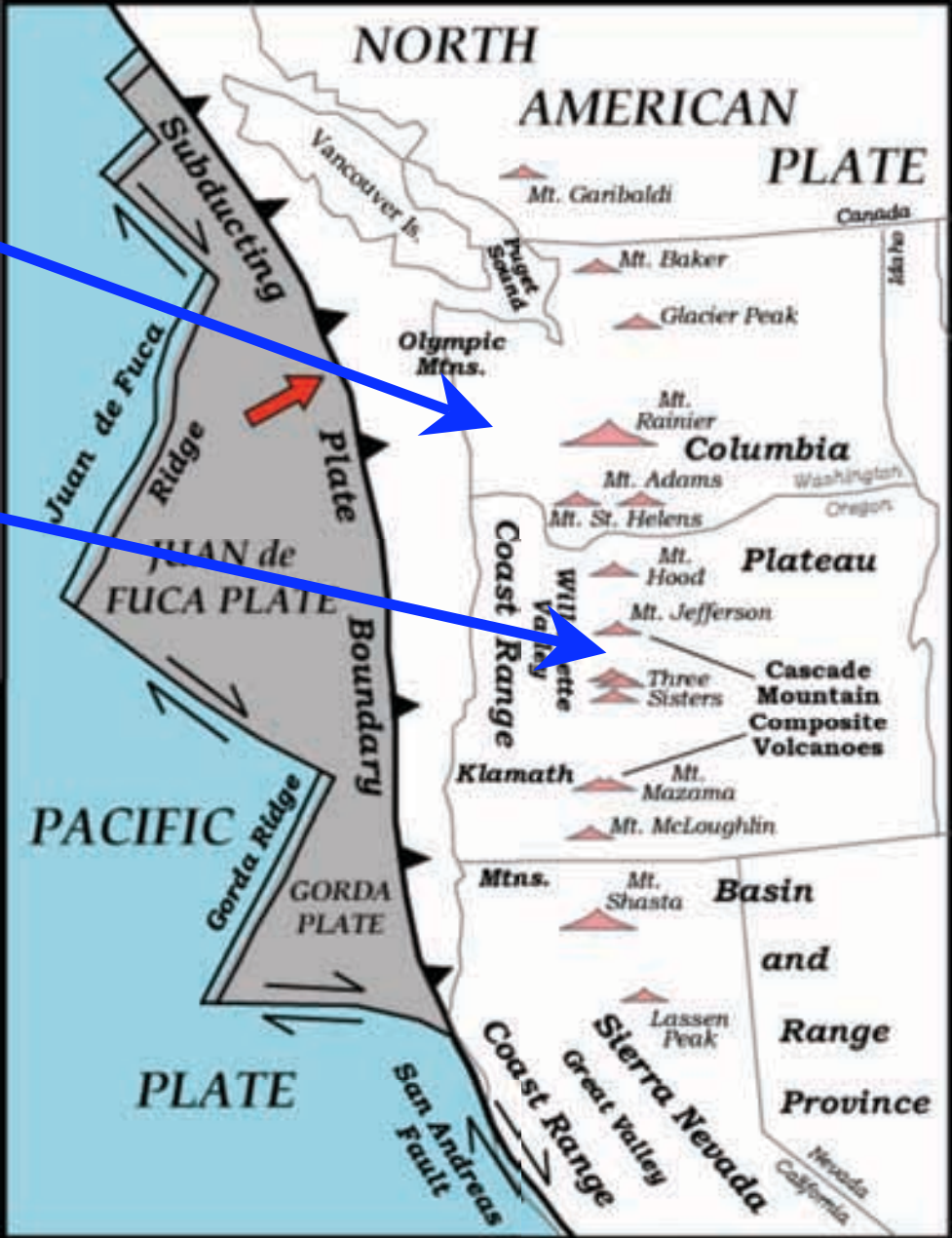
*Mt. Rainier National Park,
Washington*



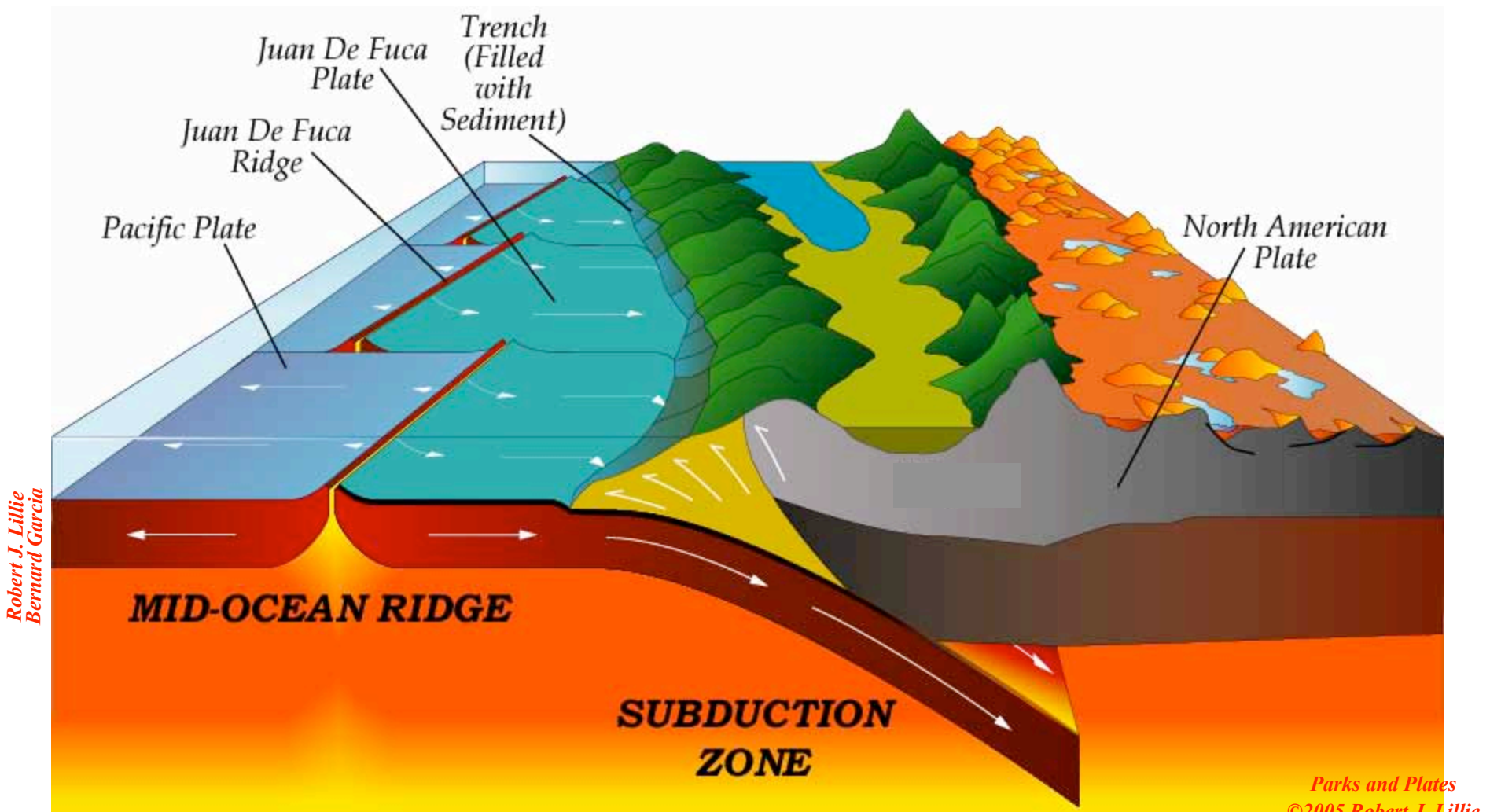
Coastal Ranges

Cascade Volcanoes

Subduction of the Juan de Fuca Plate forms the Coastal Ranges and Cascade Volcanoes

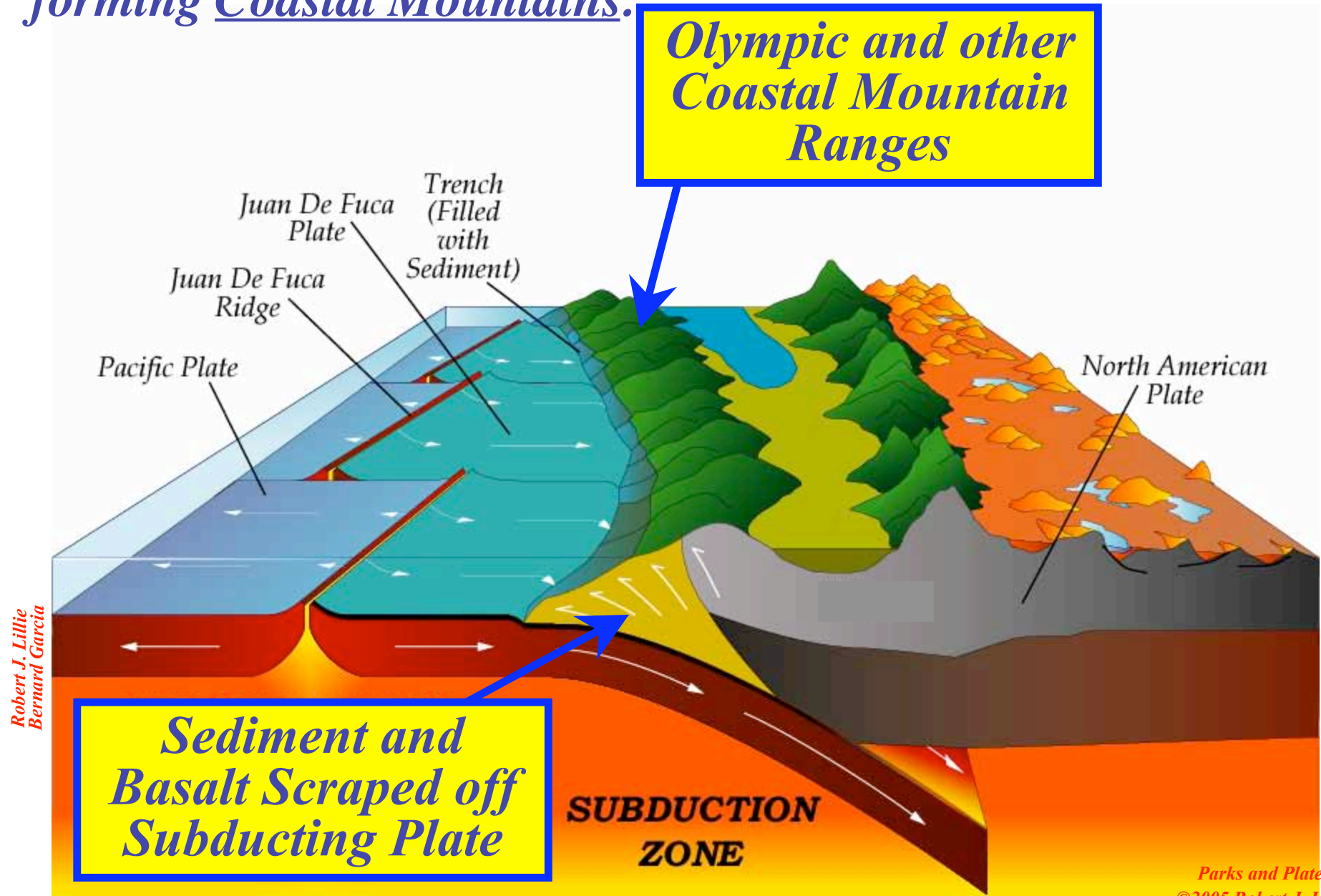


Subducting Juan de Fuca Plate forms two parallel mountain ranges in the Pacific Northwest.



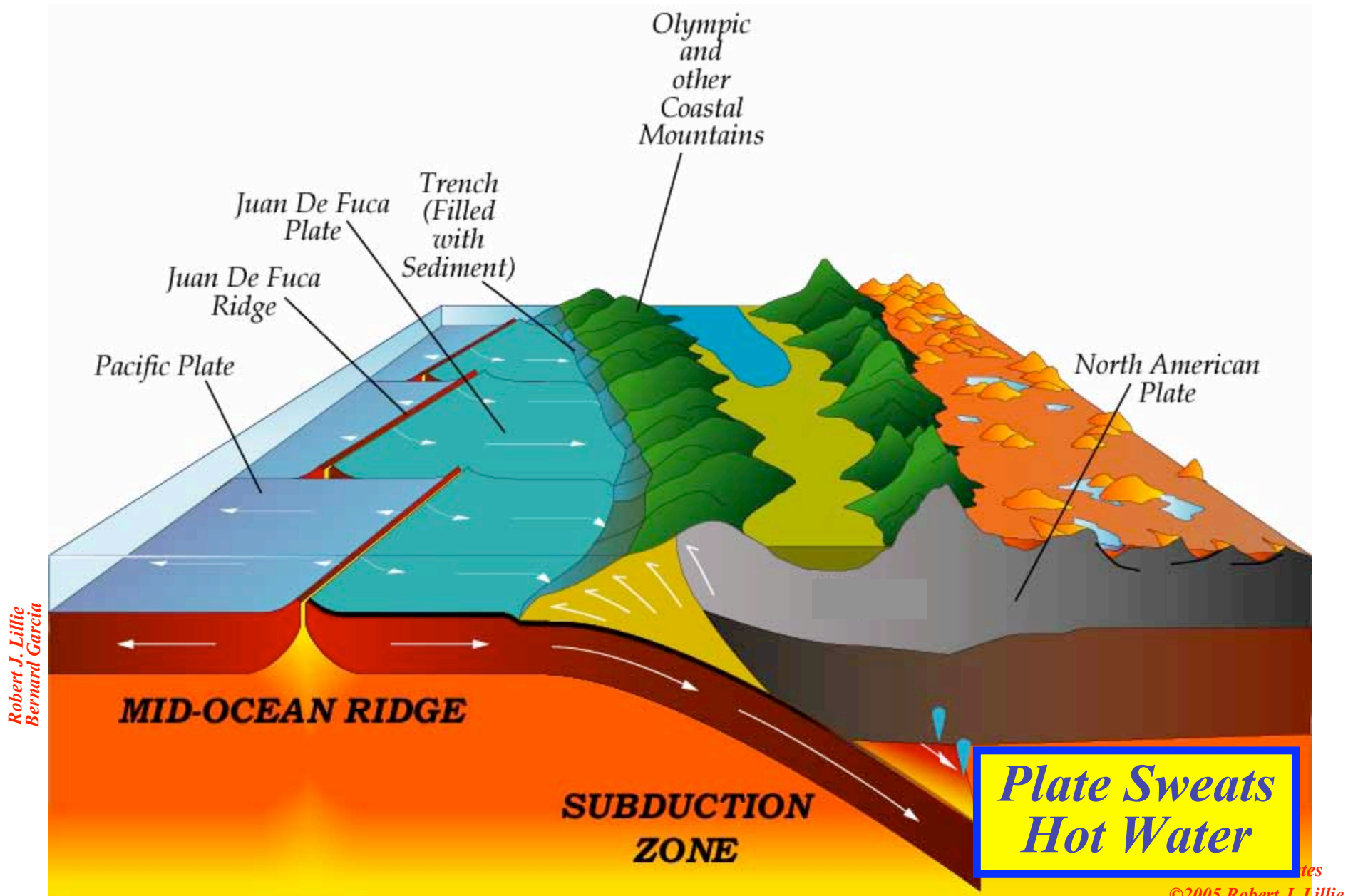
Robert J. Lillie
Bernard Garcia

Oceanic sediment and basalt scraped off subducting plate, forming Coastal Mountains.

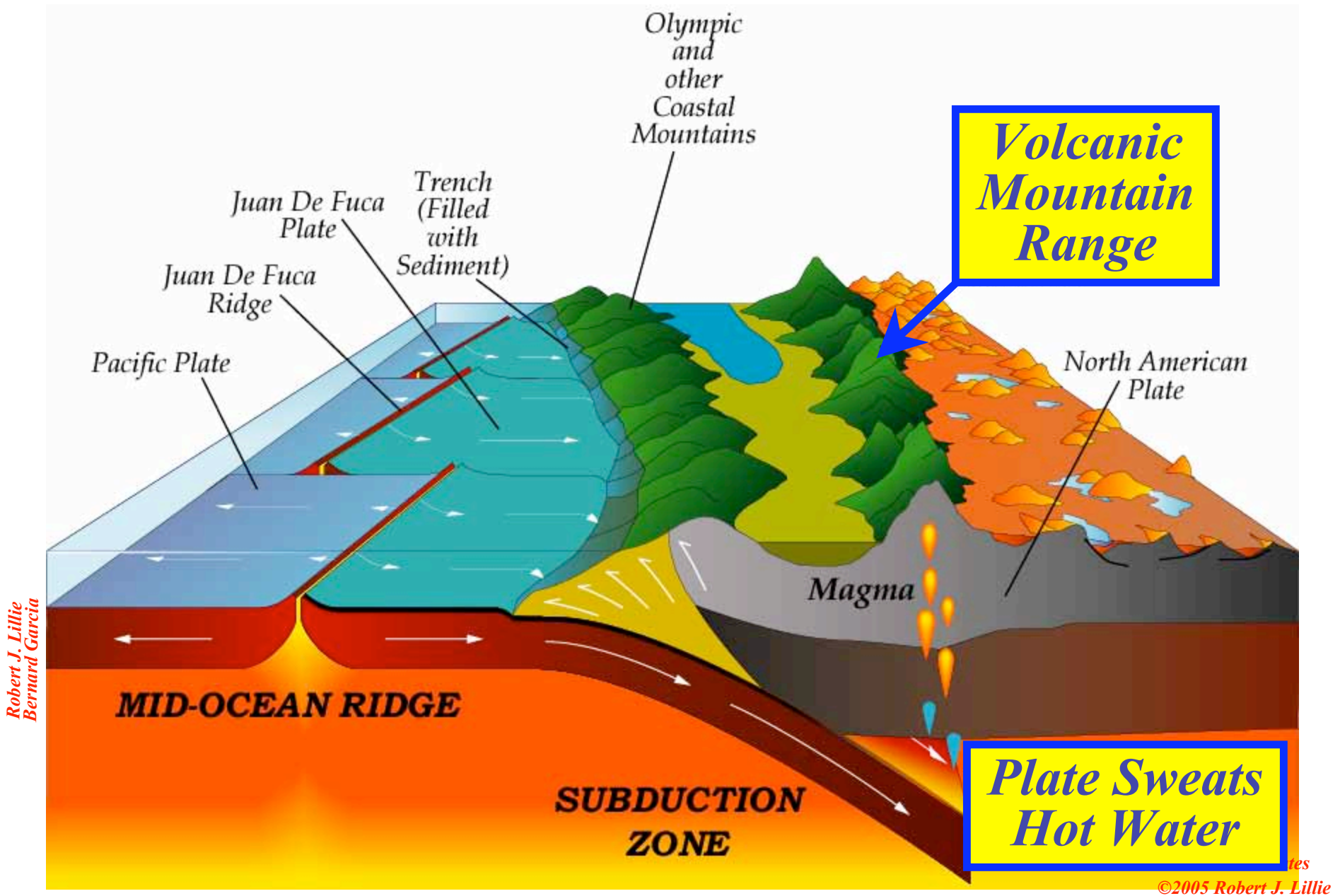


Robert J. Lillie
Bernard Garcia

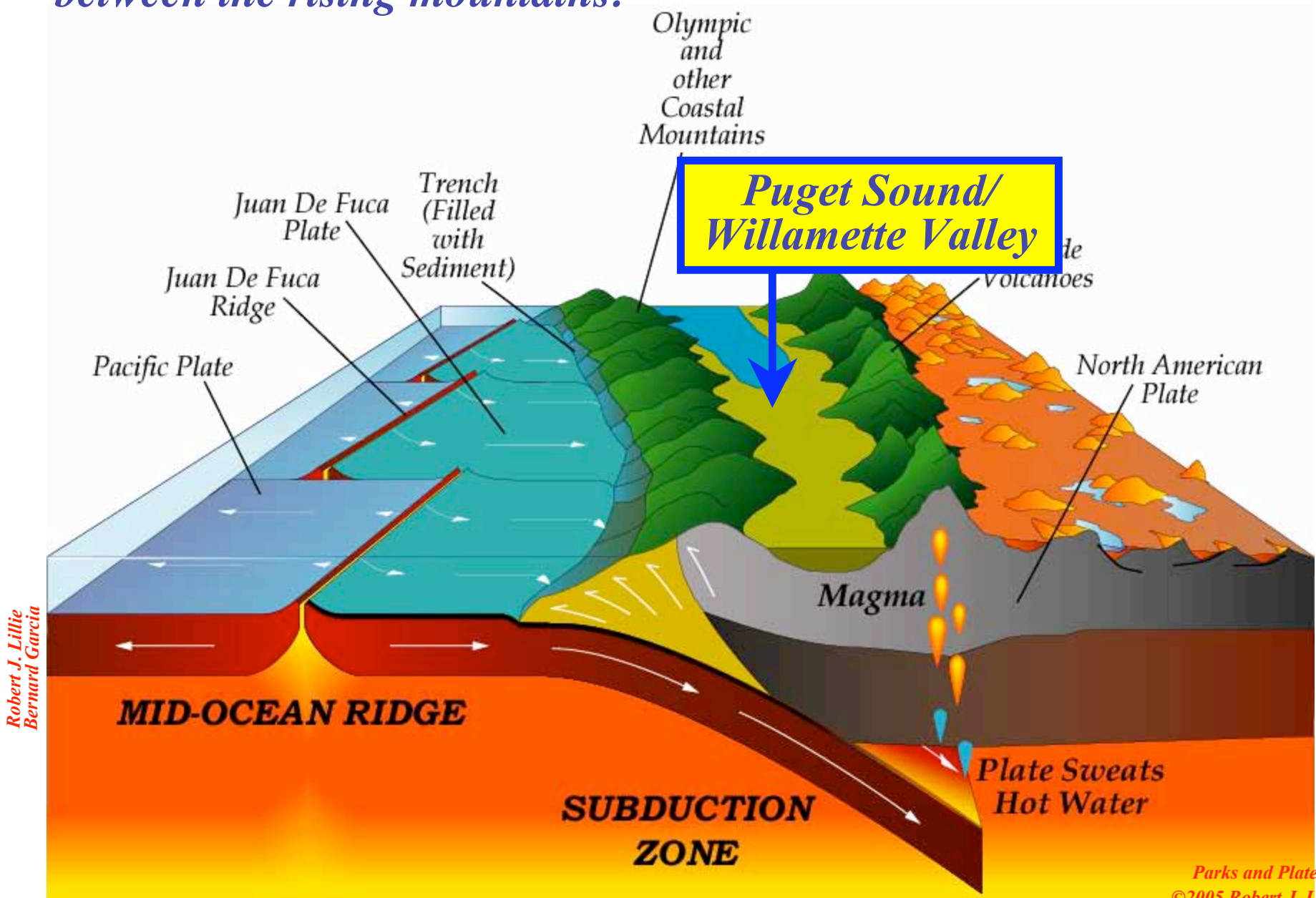
Subducting plate dehydrates, forming Cascade Volcanoes.



Subducting plate dehydrates, forming Cascade Volcanoes.



Puget Sound and the Willamette Valley are low-lying regions between the rising mountains.



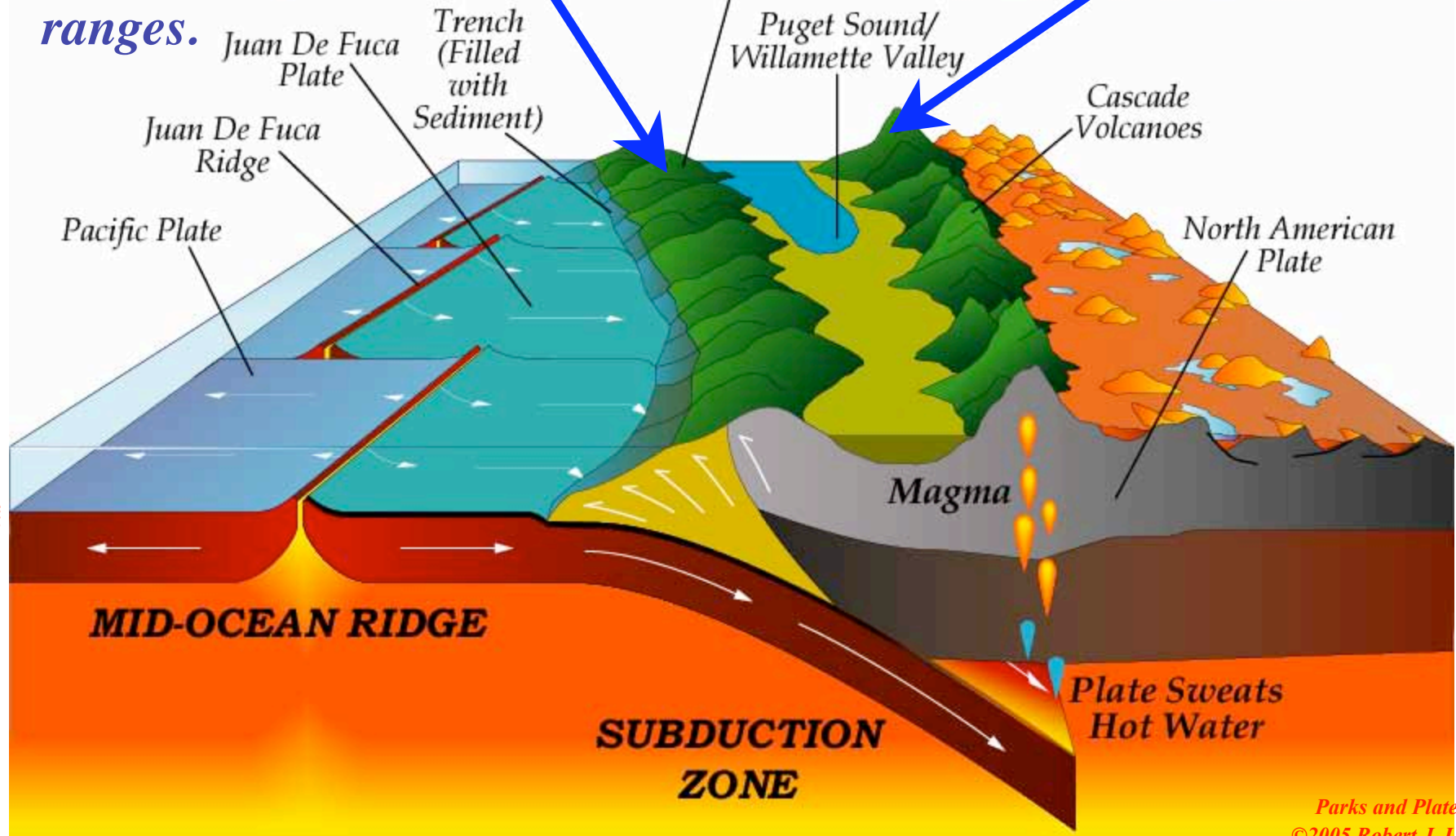
Robert J. Lillie
Bernard Garcia

Parks and Plates
©2005 Robert J. Lillie

National Parks represent the two different mountain ranges.



Olympic and other Coastal Mountains



Robert J. Lillie
Bernard Garcia

Marys Peak Recreation Area, Oregon

Cascades

Willamette Valley

Coast Range



View across Willamette Valley to Three Sisters



Cascades

Willamette Valley

Coast Range

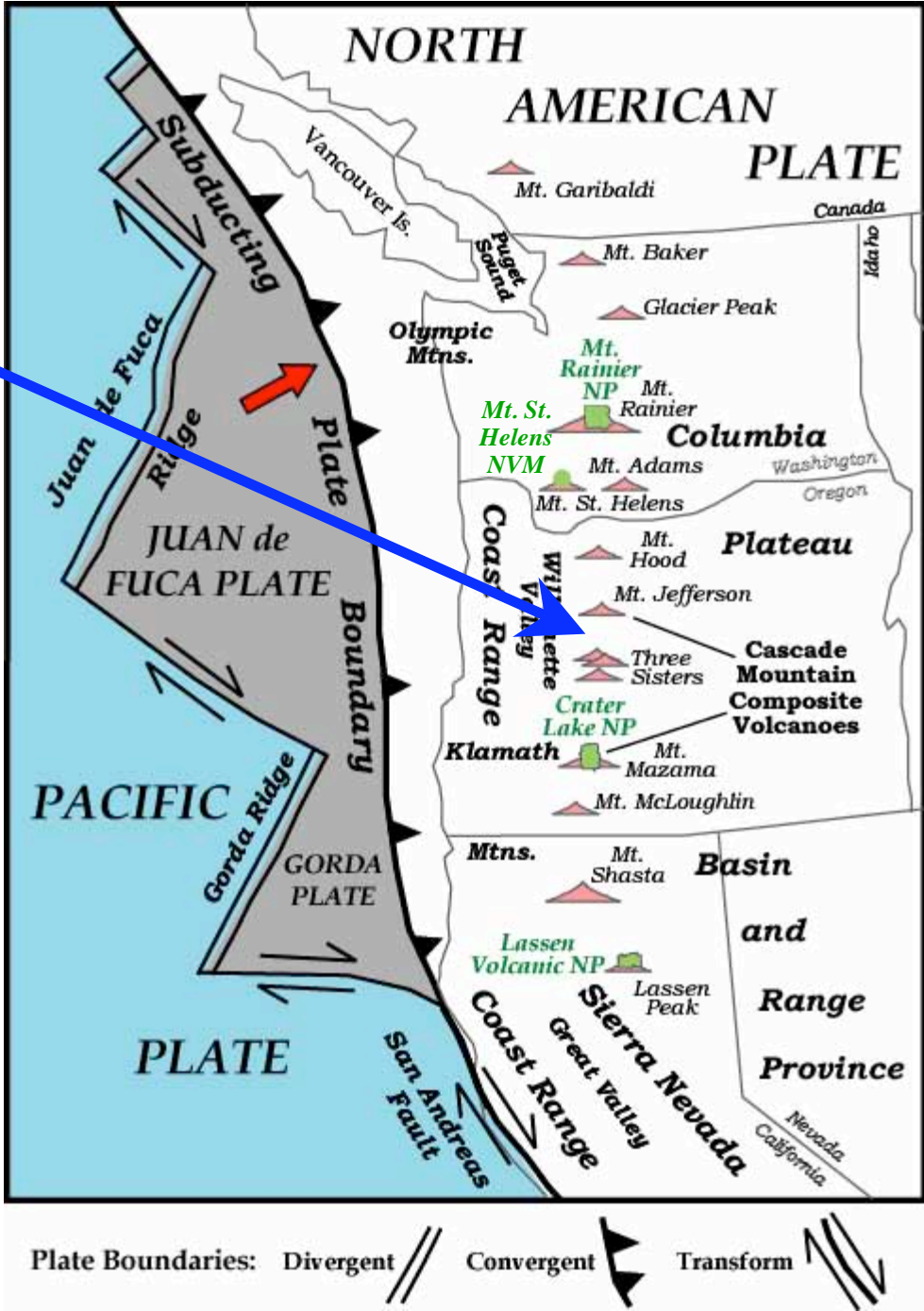
Robert J. Little

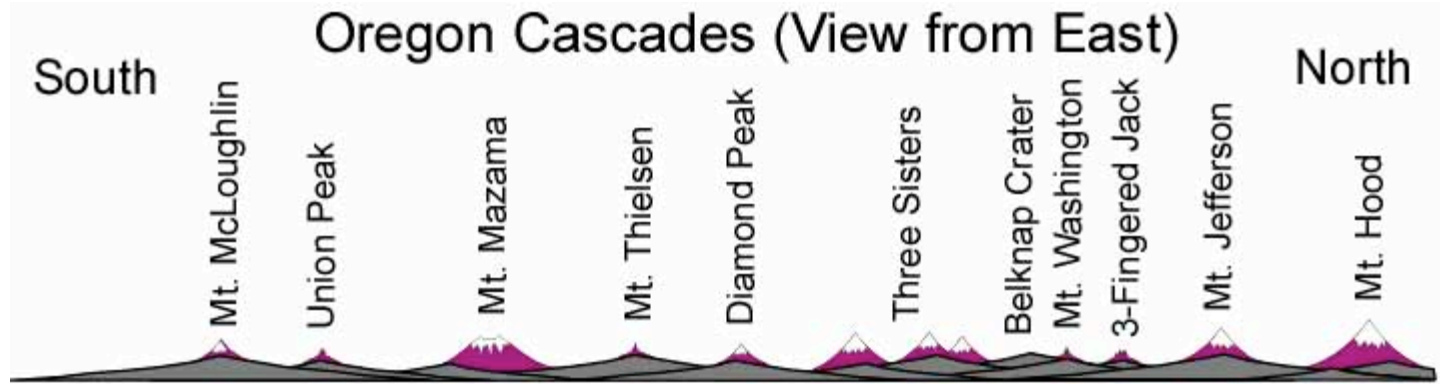
Marys Peak Recreation Area, Oregon

*Cascade
Volcanoes*

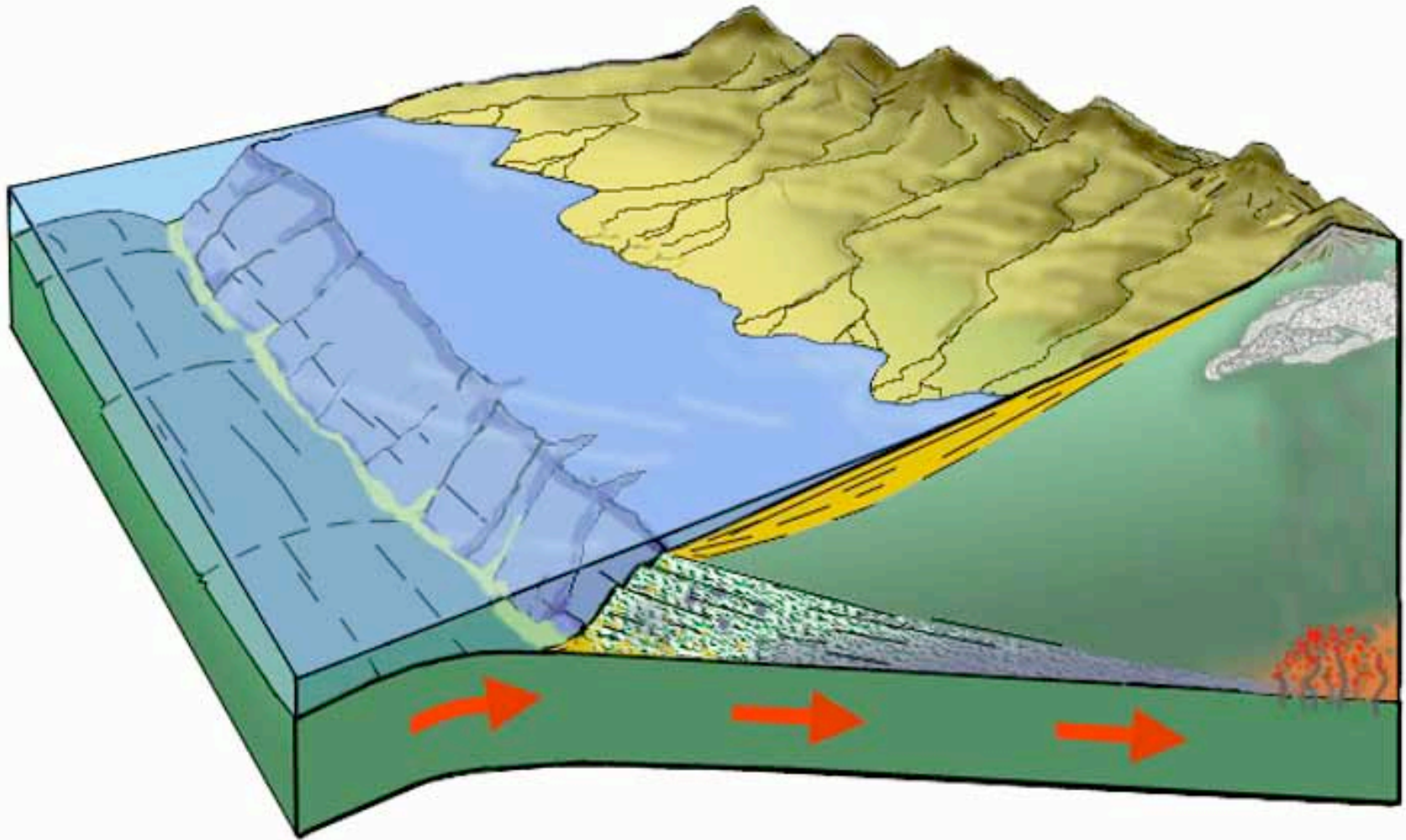
*Parks in the Cascades
showcase volcanoes
formed above the
subducting plate.*

**National Park Lands in
Active Volcanic Arc**





Why are the Cascade Volcanoes in such a straight line?



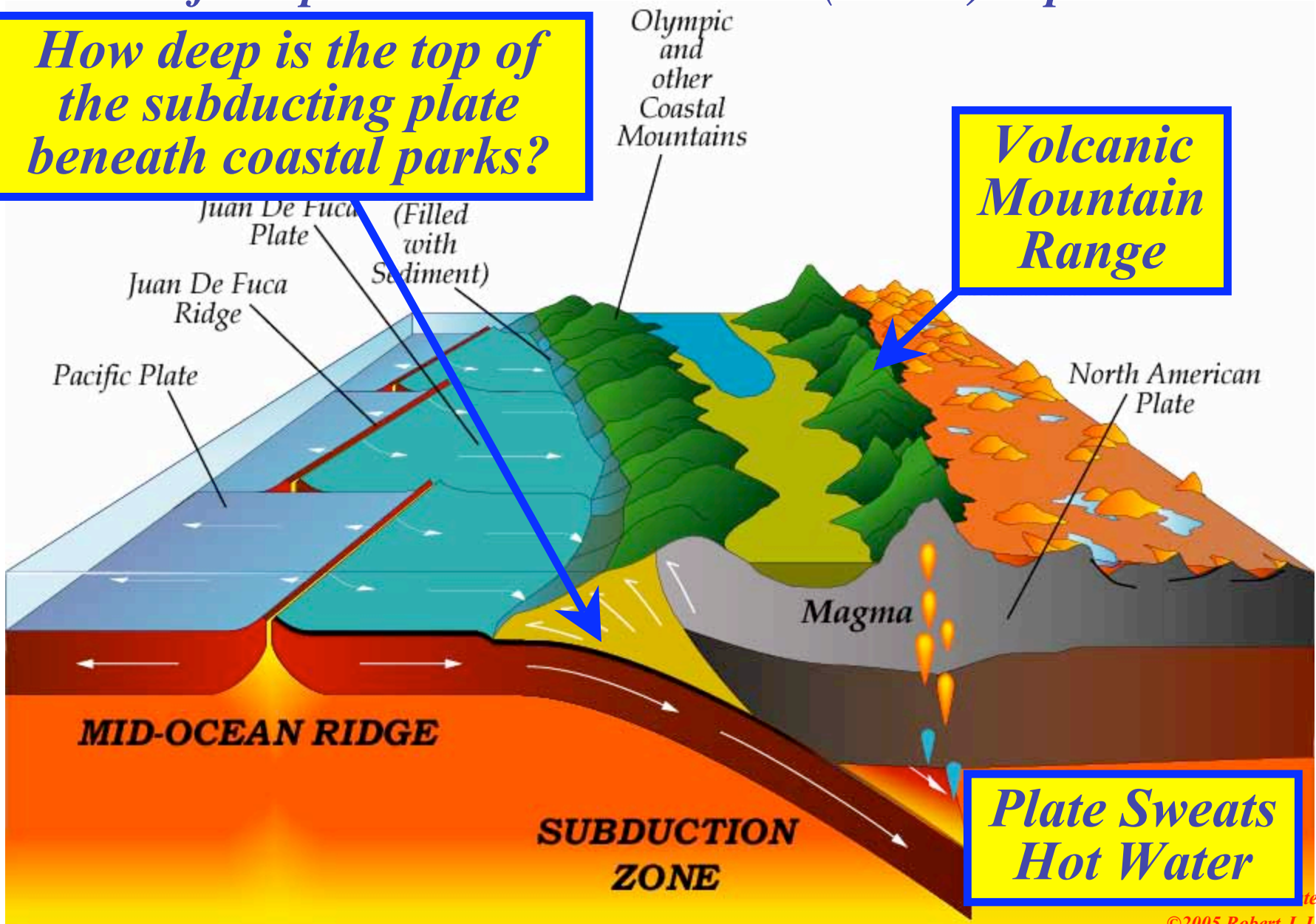
<http://emvc.geol.ucsb.edu> (Animation by Tanya Atwater - Time 0:13)

The Cascade Volcanoes form above the line where the top of the plate reaches ~ 50 miles (80 km) depth.

How deep is the top of the subducting plate beneath coastal parks?

Olympic and other Coastal Mountains

Volcanic Mountain Range



Robert J. Lillie
Bernard Garcia

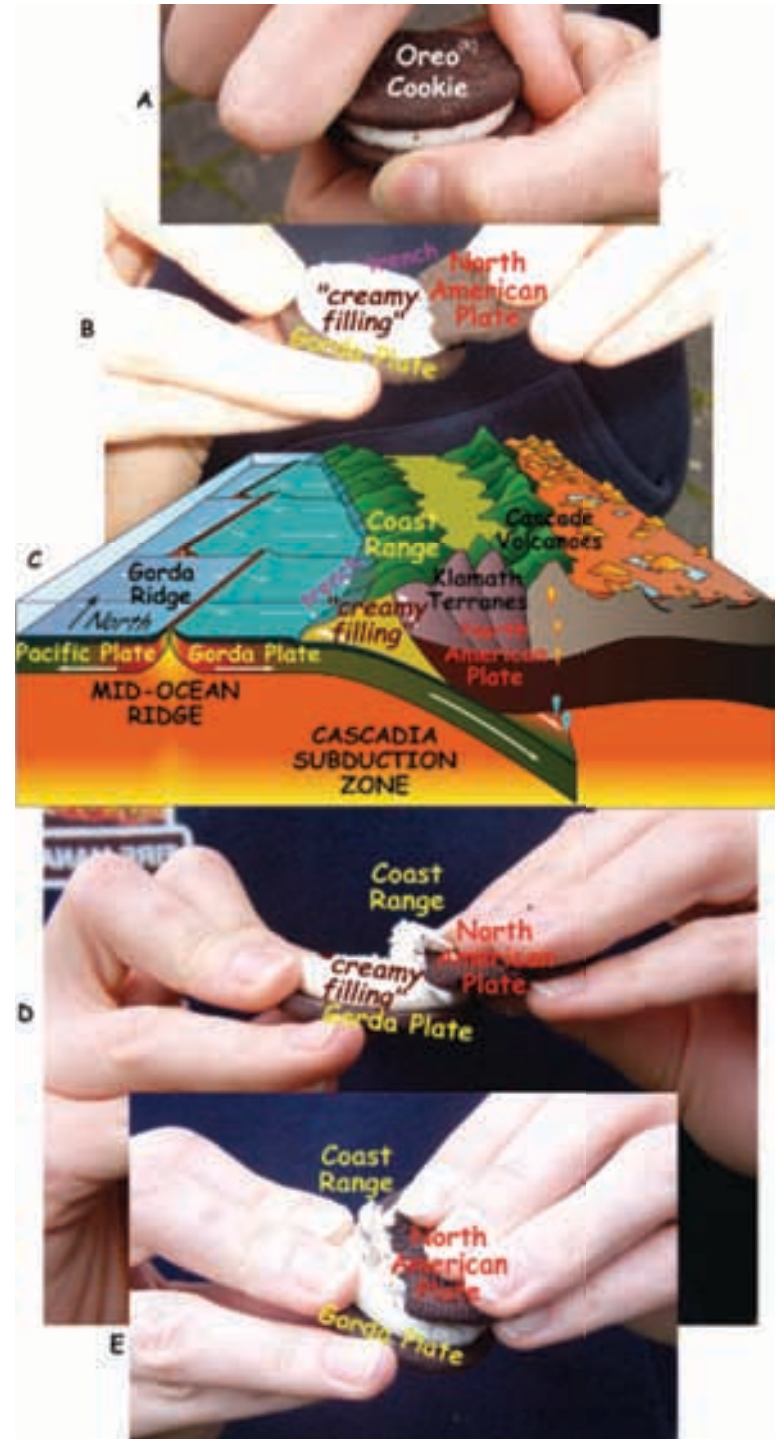
Plate Sweats Hot Water

The Coast Range contains Basalt and Sedimentary Layers originally deposited on the Floor of the Ocean



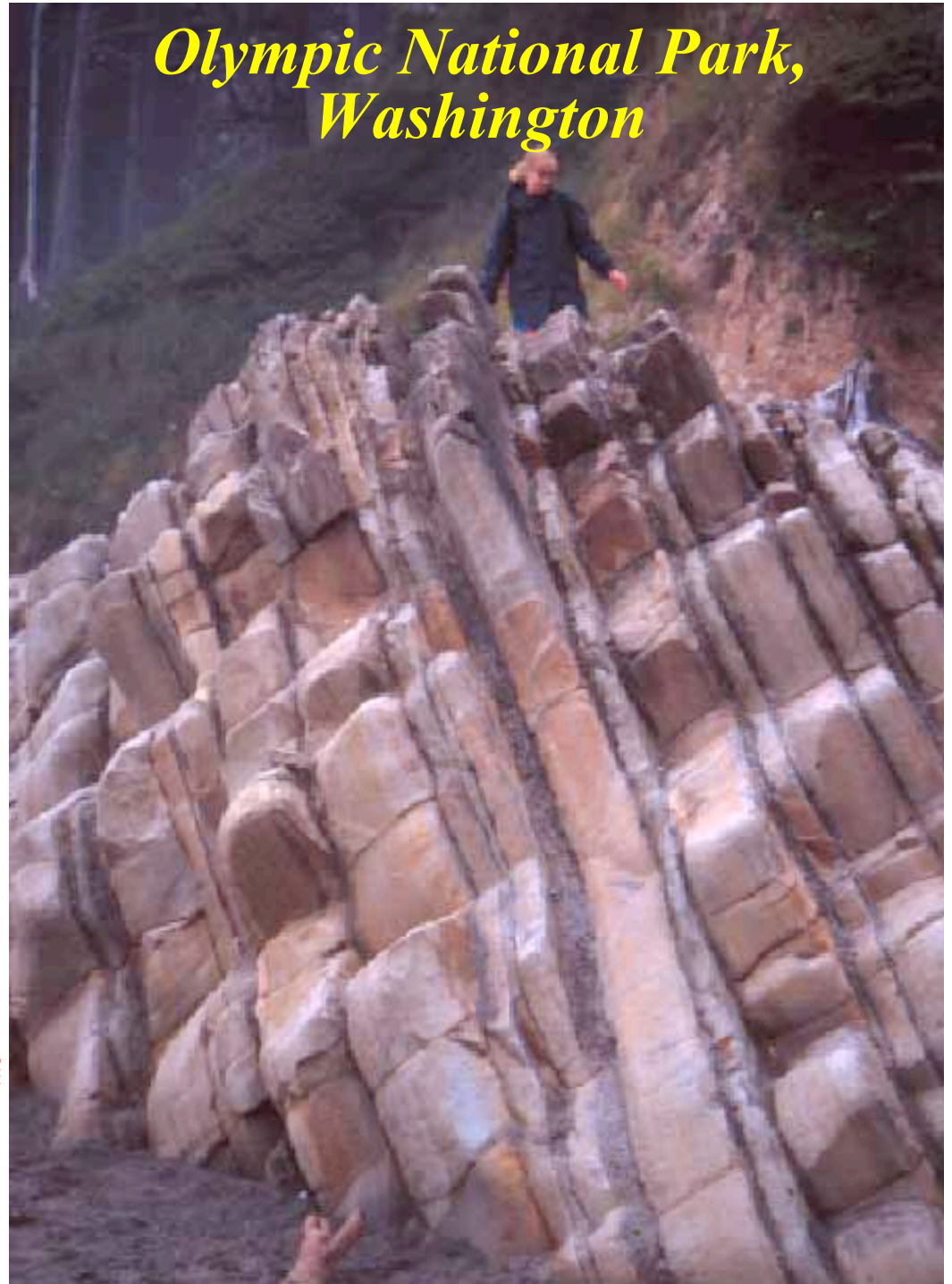
Ranger Jen's Oreo Subduction Demo

Coast ranges are material scraped off the ocean floor.



Coastal Ranges

*Layers Lifted out of
the Sea*





Tyee Formation
Marine Sandstones and Shales
~ 45 Million Years Old (Middle Eocene)

Robert J. Little

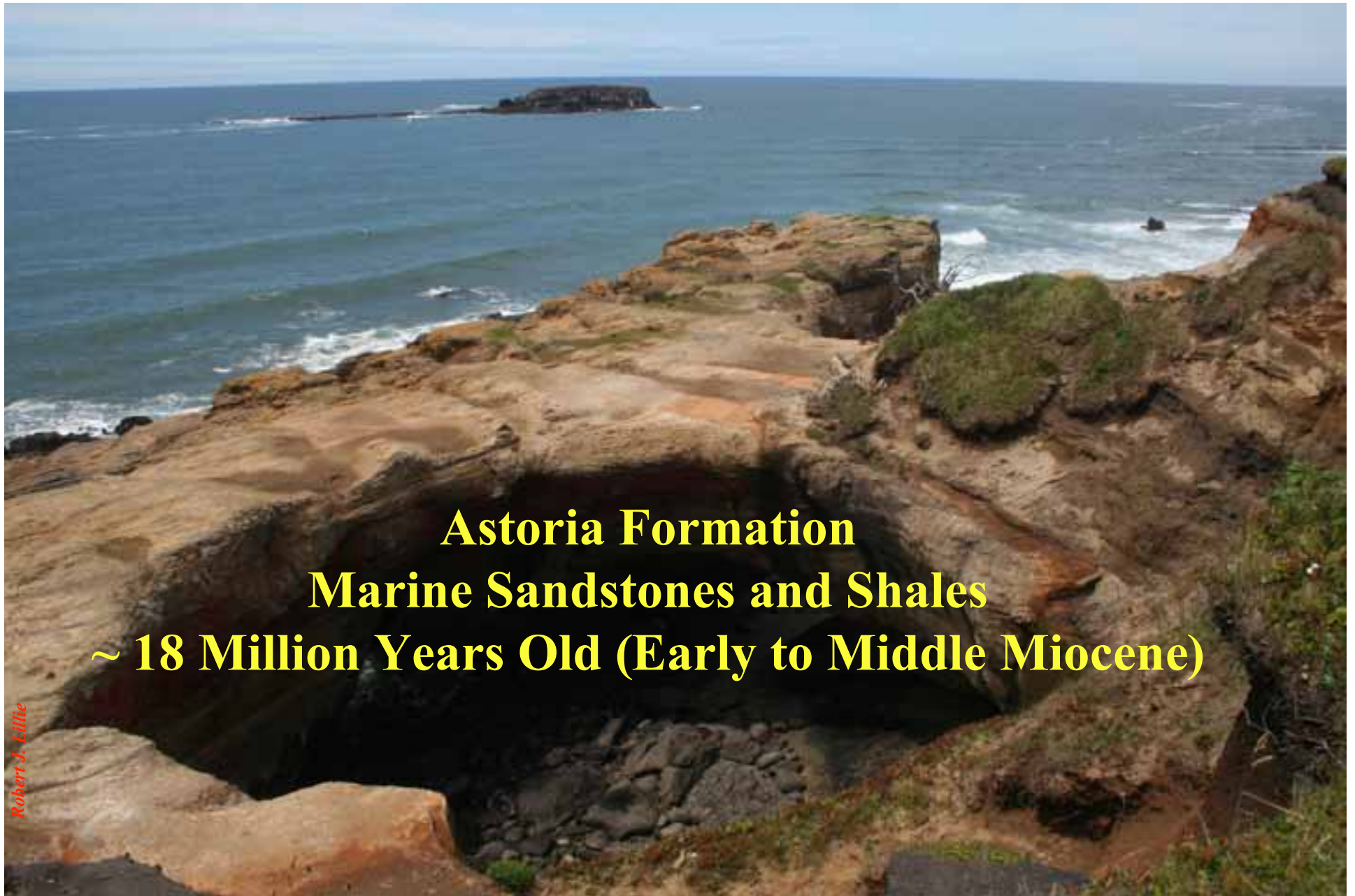
Marys Peak Recreation Area, Oregon



Tyee Formation
Marine Sandstones and Shales
~ 45 Million Years Old (Middle Eocene)

Robert J. Lillie

Marys Peak Recreation Area, Oregon



Devils Punch Bowl State Natural Area, Oregon



**Astoria Formation
Marine Sandstones and Shales
~ 18 Million Years Old (Early to Middle Miocene)**

Robert J. Lillie

Devils Punch Bowl State Natural Area, Oregon



**Yaquina Formation
Marine Sandstones and Shales
~ 22 Million Years Old (Early Miocene)**

Robert J. Little

Beverly Beach State Park, Oregon

*Beverly Beach State Park,
Oregon*

**Yaquina Formation
Marine Sandstones and Shales
~ 22 Million Years Old
(Early Miocene)**



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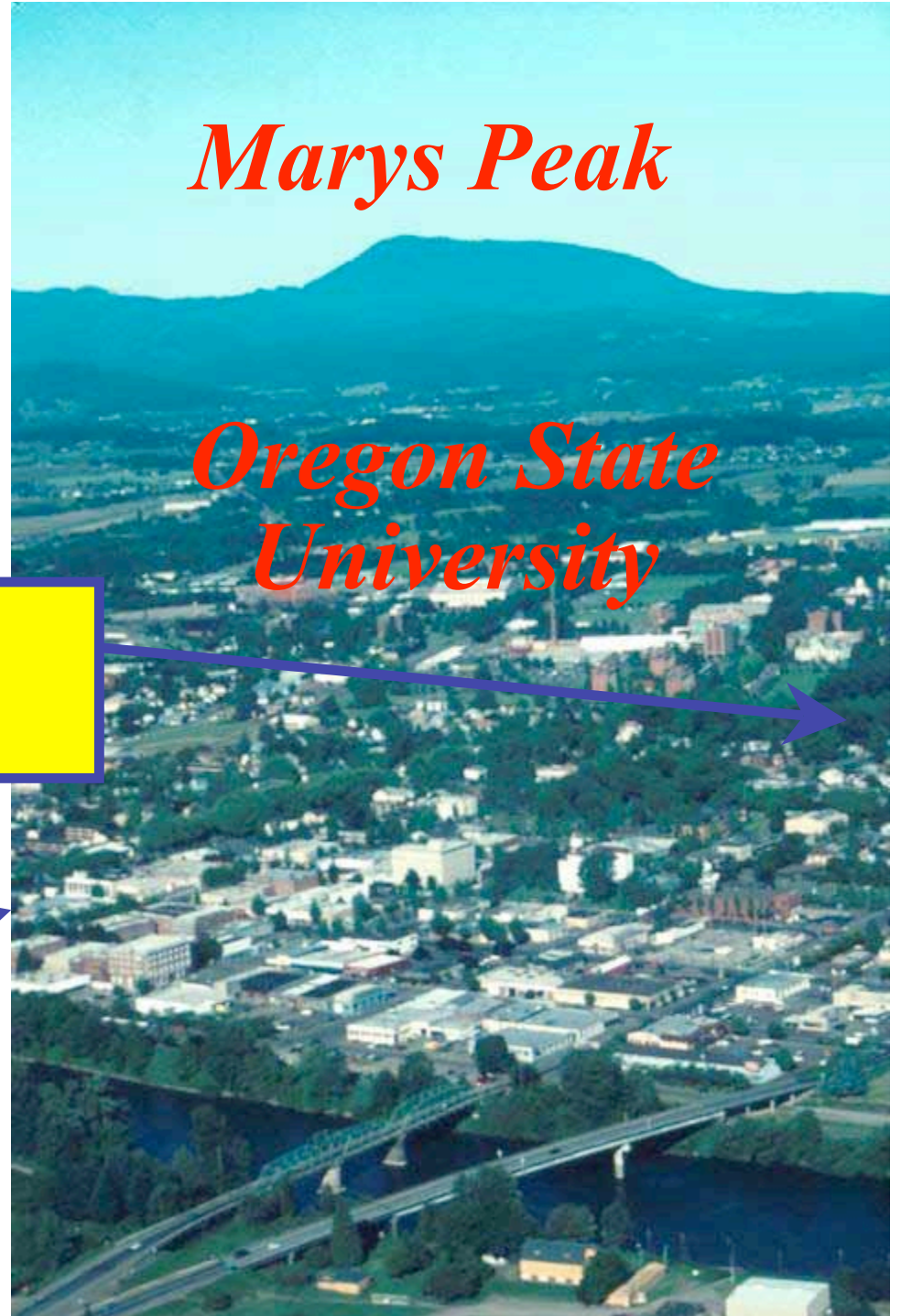
Corvallis, Oregon

Marys Peak

*Oregon State
University*

*Campus
Beanery*

*Downtown
Beanery*



Basalt Lava Flows

- Manufactured in Ocean Realm
- About 55 million years ago

Robert J. Little

Marys Peak



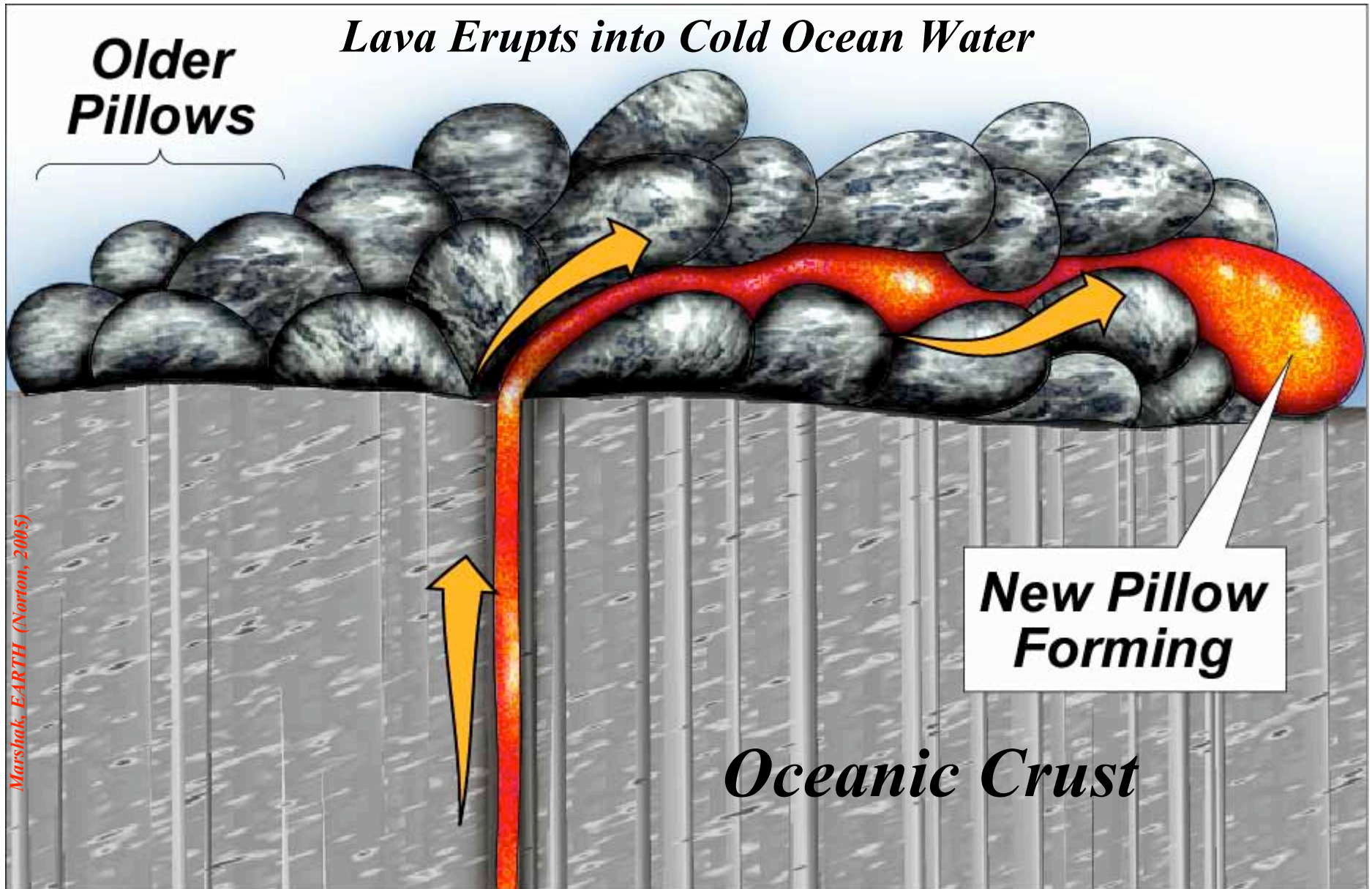
Formation of Pillow Lava



The formation of pillow lava in the deep ocean has never been observed, but it probably looks a lot like this. This movie shows pillow lava flowing underwater off the coast of Hawaii, after it was erupted on land and flowed into the ocean. Video footage from the movie "Pele Meets the Sea" courtesy of Richard Pyle (deepreef@bishopmuseum.org) at Lava Video Productions.

http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/media/pillow_lava_video.html

Formation of Pillow Lava

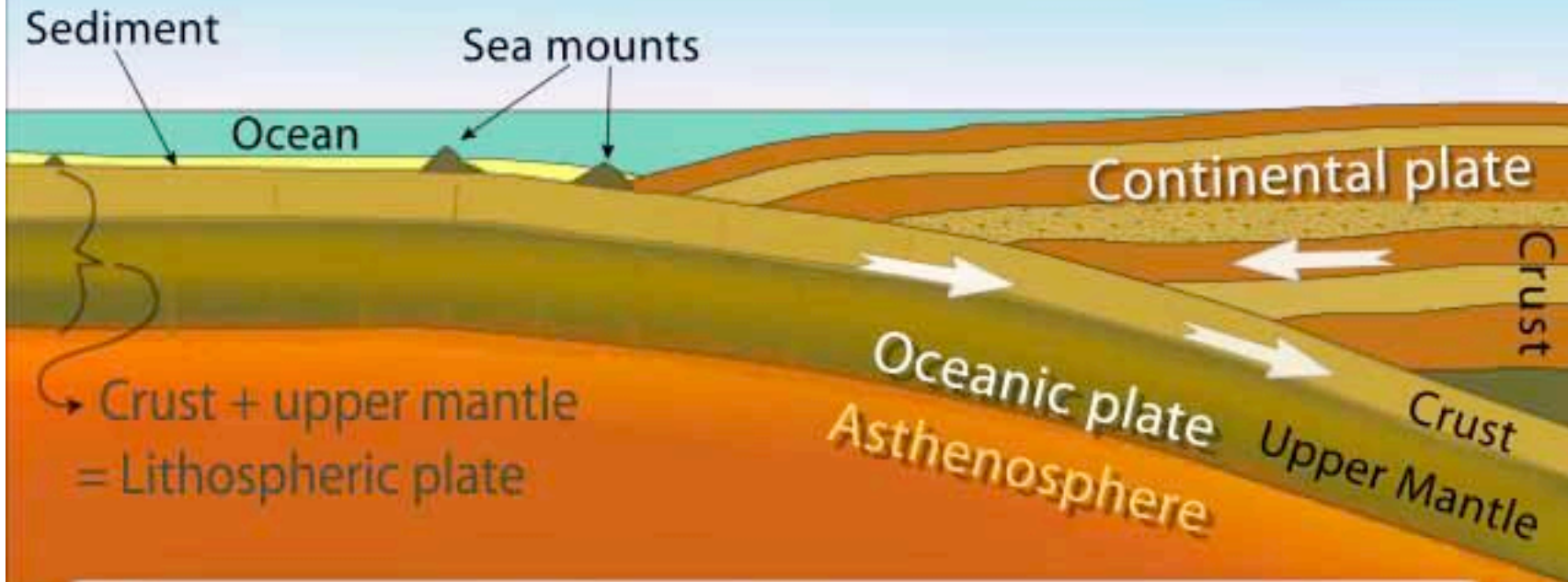


**Siletz River Volcanics
Oceanic Basalt Lava Flows
~ 55 Million Years Old (Early Eocene)**

Robert J. Lillie

Marys Peak Recreation Area, Oregon

Convergent Boundary— Ocean-continent Subduction



Processes at the boundary:

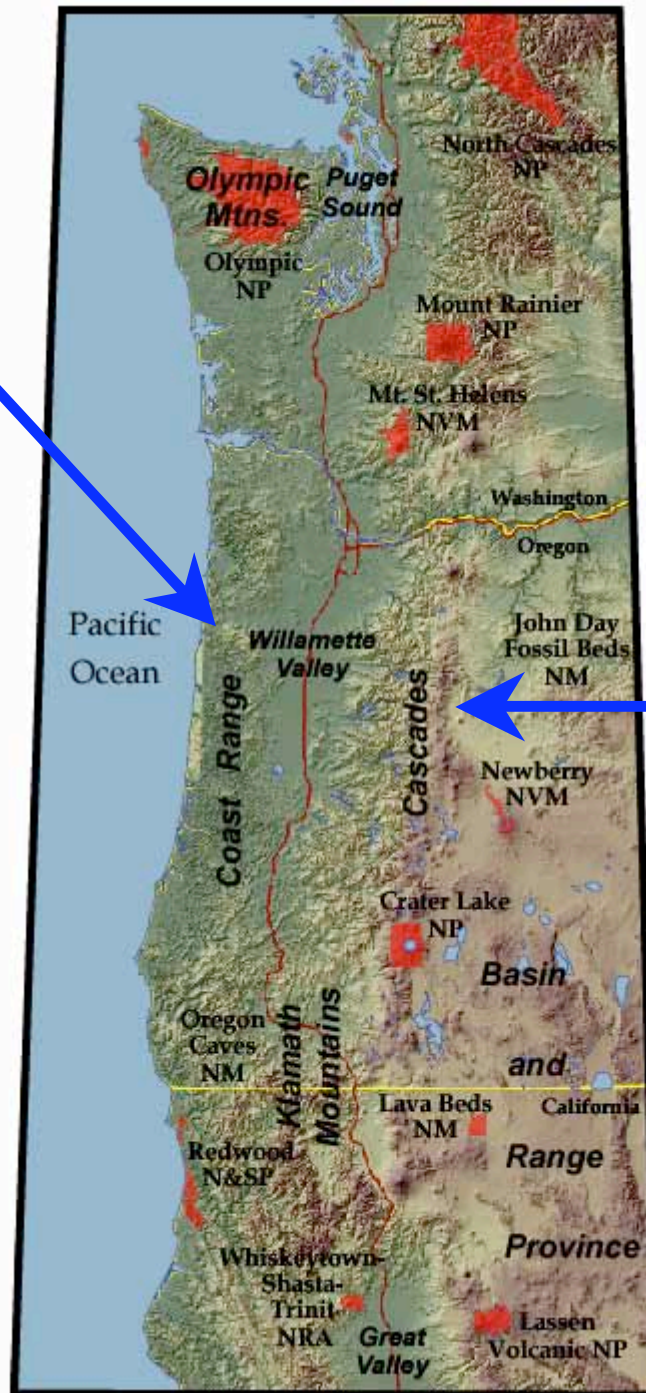
- 1) Plates locked = stress & deformation
- 2) Plates release = earthquake & tsunami

Scale is greatly exaggerated. Volcanic processes occur farther inland.

Coastal Ranges

1. Why are there two parallel mountain ranges in the Pacific Northwest?

2. Why are there earthquakes, tsunamis and volcanic eruptions?



Cascade Volcanoes

**National Park
Lands in the
Pacific Northwest**

Active Tectonics of the Pacific Northwest

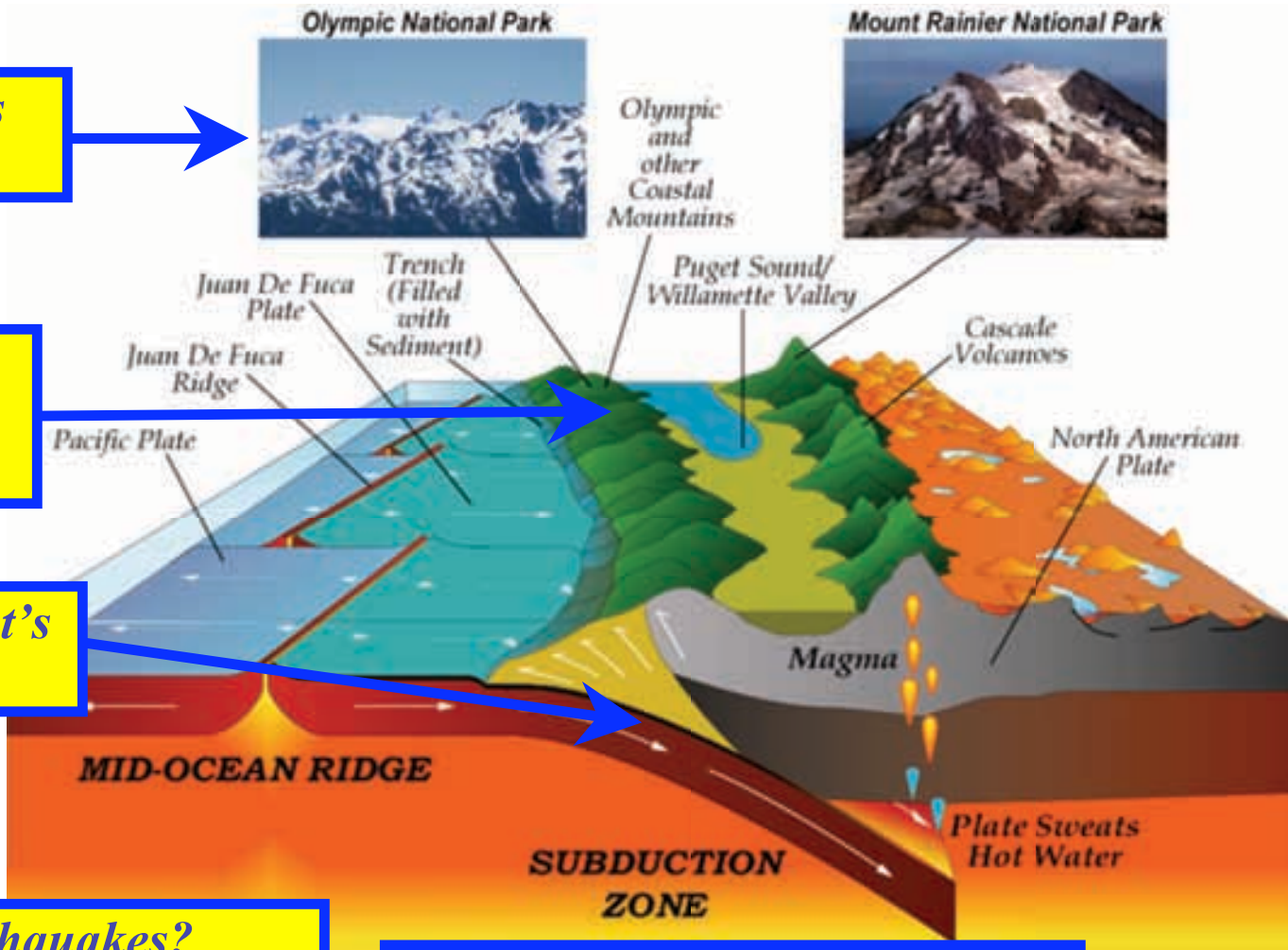
We can see what's on the surface.



Olympic and other Coastal Mountains

How does the surface change as a response to subduction?

How do we know what's beneath the surface?



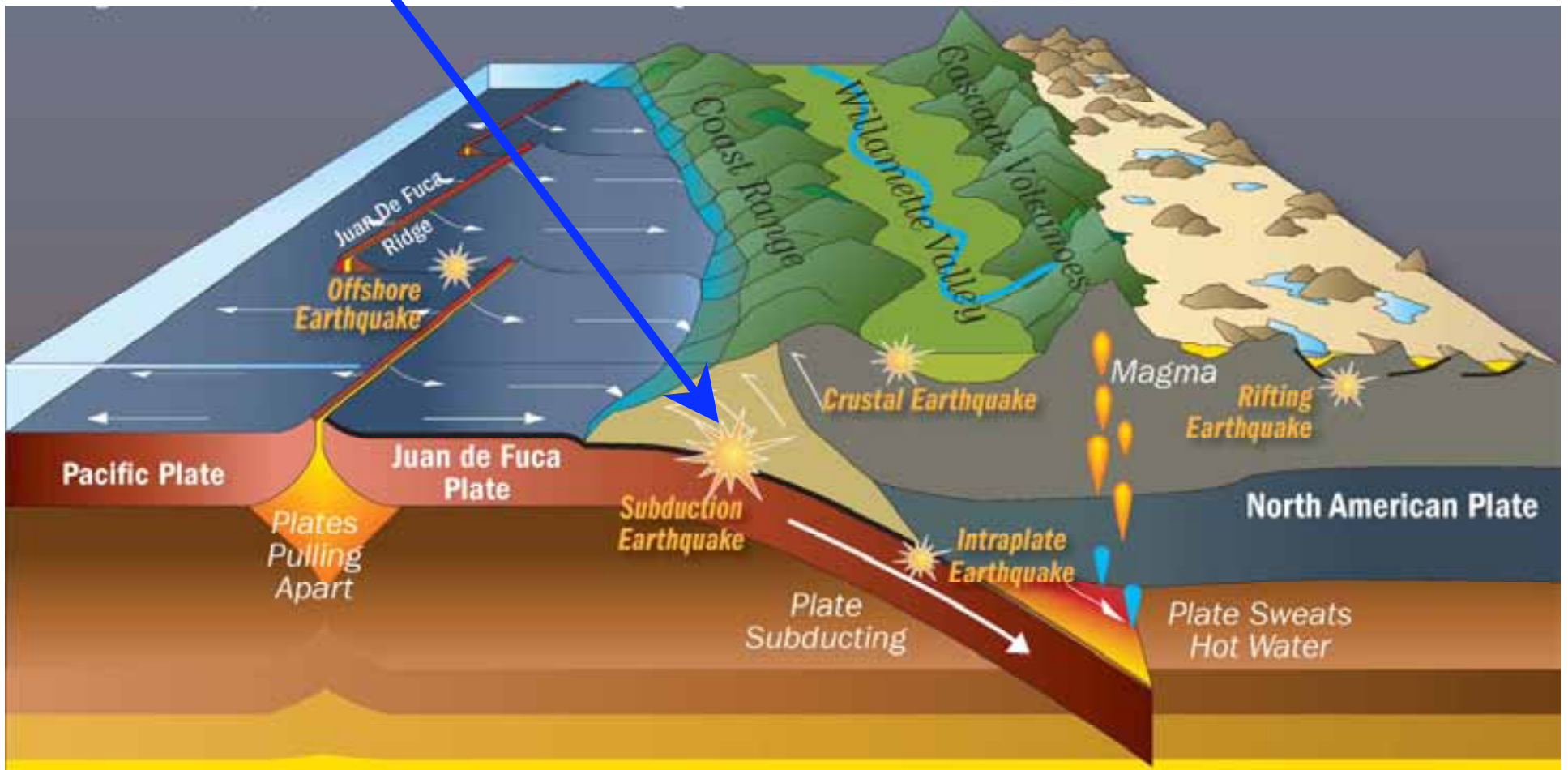
- Where are the earthquakes?
- Why are they there?
- How often does each type occur?

- How big is each type?
- How destructive is each type?

Oregon Earthquakes

“The Big One” occurs when plates lock for centuries, then suddenly let go!

Big Ones happen every 200 to 600 years. The last one was in the year 1700





Four Types of Earthquakes in Cascadia Subduction Zone

1) Slab Earthquakes:

- Within Juan de Fuca Plate
- Up to 40 miles (60 km) depth
- Up to Magnitude 7

2) Locked Zone (Mega-Thrust) Earthquakes:

- Between Juan de Fuca and North American Plates
- 5 - 10 miles (8 - 15 km) depth
- Up to Magnitude 9

3) Upper Plate Earthquakes:

- Within North American Plate
- 1 - 10 miles (2 - 15 km) depth
- Up to Magnitude 7

4) Volcanic Earthquakes:

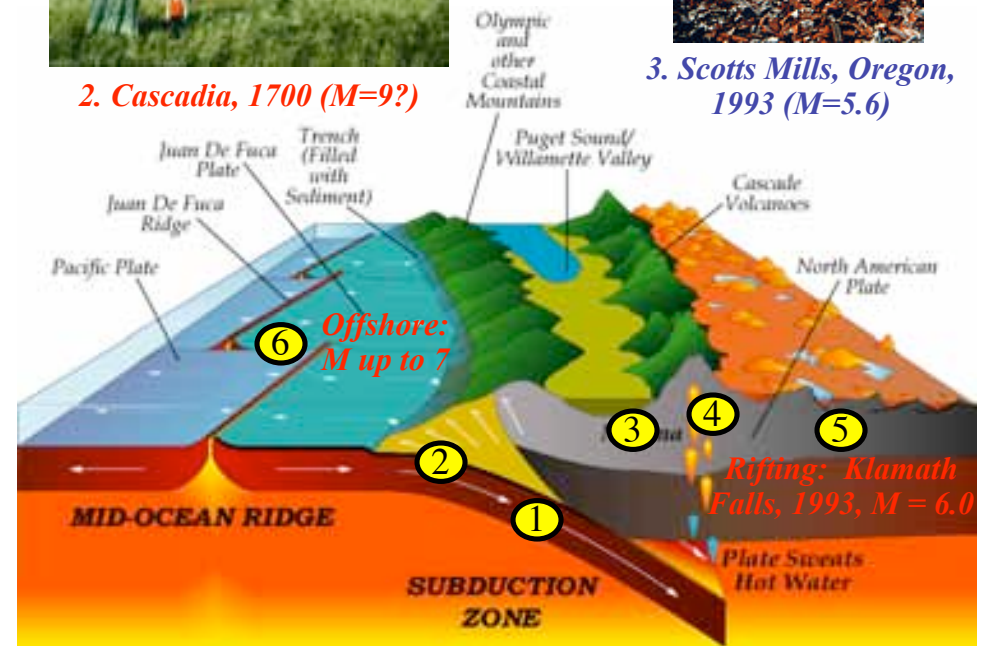
- From magma shallowing beneath Cascade volcanoes
- 1 - 5 miles (2 - 10 km) depth
- Up to Magnitude 5.5



2. Cascadia, 1700 (M=9?)



3. Scotts Mills, Oregon, 1993 (M=5.6)



1. Nisqually, Washington, 2001 (M=6.9)



4. Mt. St. Helens, Washington, 1980 (M=5.5)



Basalt Lava Flows
Manufactured in the Ocean
~35 million years ago, then added
to the edge of the continent.

Joe Green

Cape Perpetua Scenic Area, Oregon

**Yachats Formation
Oceanic Basalt Lava Flows
~ 35 Million Years Old (Late Eocene - Oligocene)**

Robert J. Lillie

Heceta Head Lighthouse State Scenic Viewpoint, Oregon

**What about these younger lava flows?
Only 9 – 15 million years old**



Robert J. Lillie

Seal Rock State Park, Oregon

Basalt from Columbia Plateau (15-9 Million Years Ago)

Basalt from Ocean Realm (63-29 Million Years Ago)

Middle Miocene To upper Miocene
15-9 m.y.b.p.

Upper Oligocene to lower Miocene
38-29 m.y.b.p.

Upper Eocene to lower Oligocene
43-38 m.y.b.p.

Upper Paleocene to middle Eocene
63-46 m.y.b.p.



Age of Basalt along Oregon and Washington Coasts

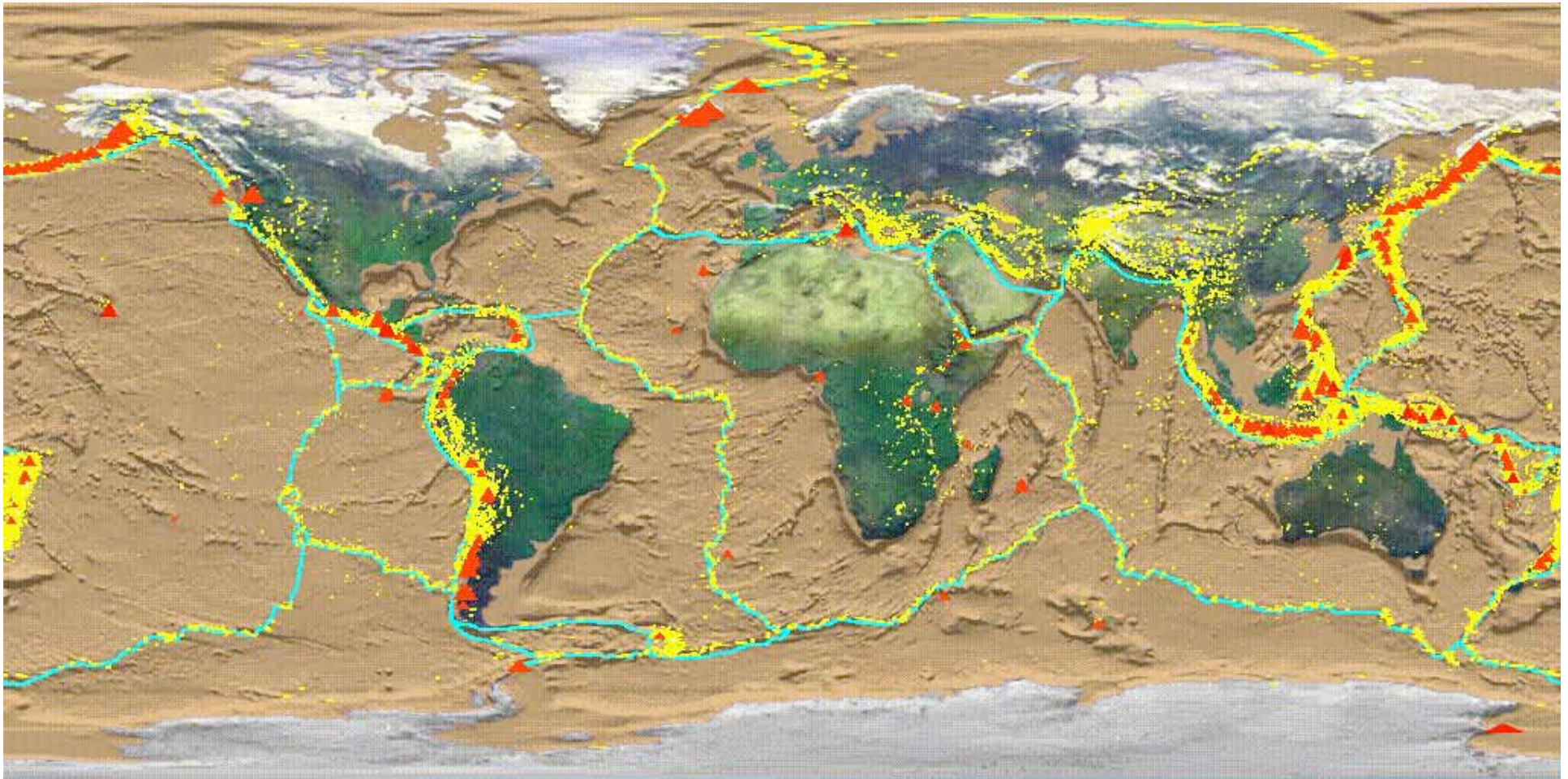
Volcanic rocks of the Oregon and Washington Coast Range (Armentrout and Suek, 1985)

Orr, Orr, and Baldwin, "Geology of Oregon," 4th Edition, 1992

Plate Boundaries

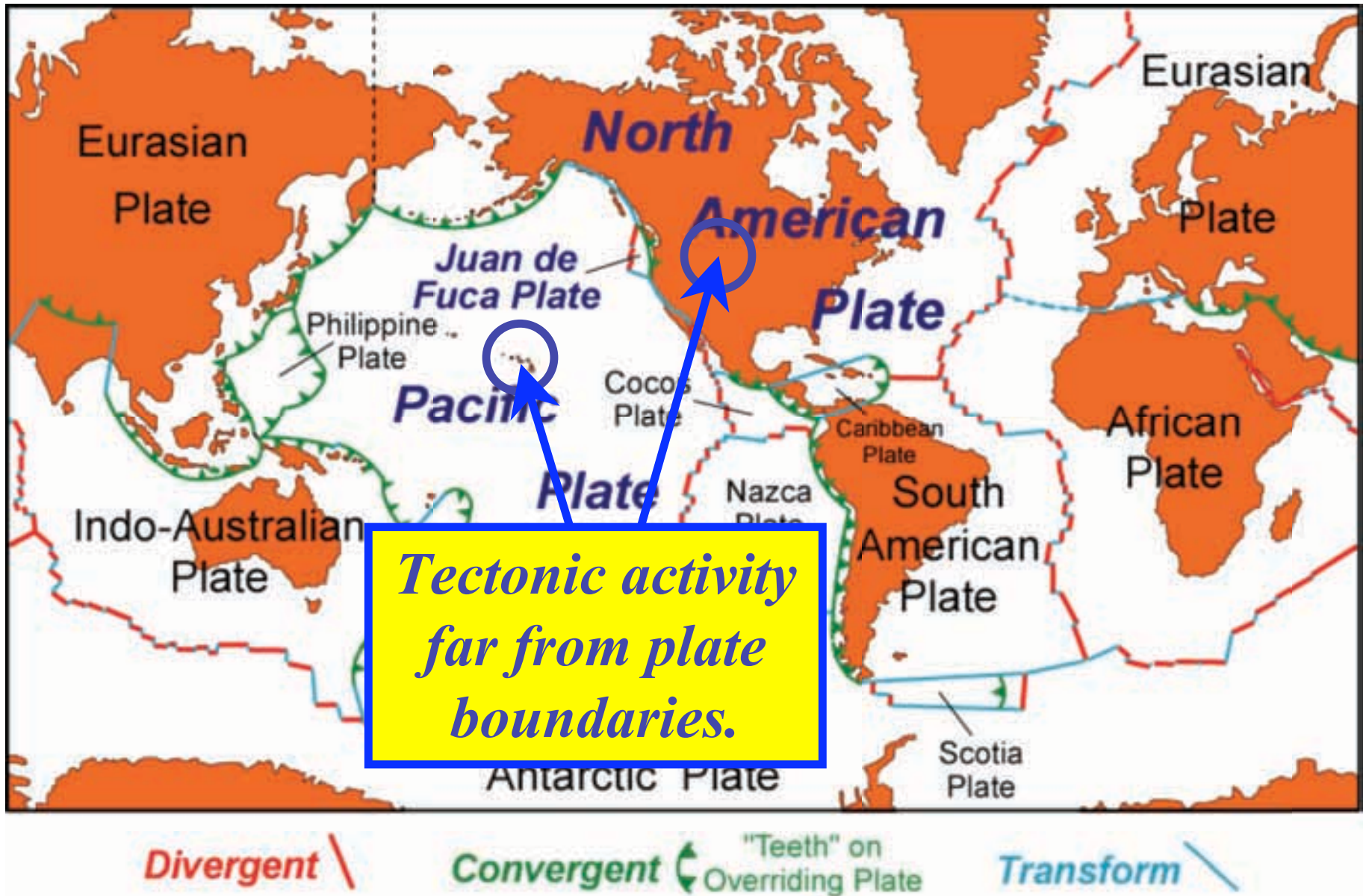
Earthquakes (yellow dots)

Active Volcanoes (orange triangles)

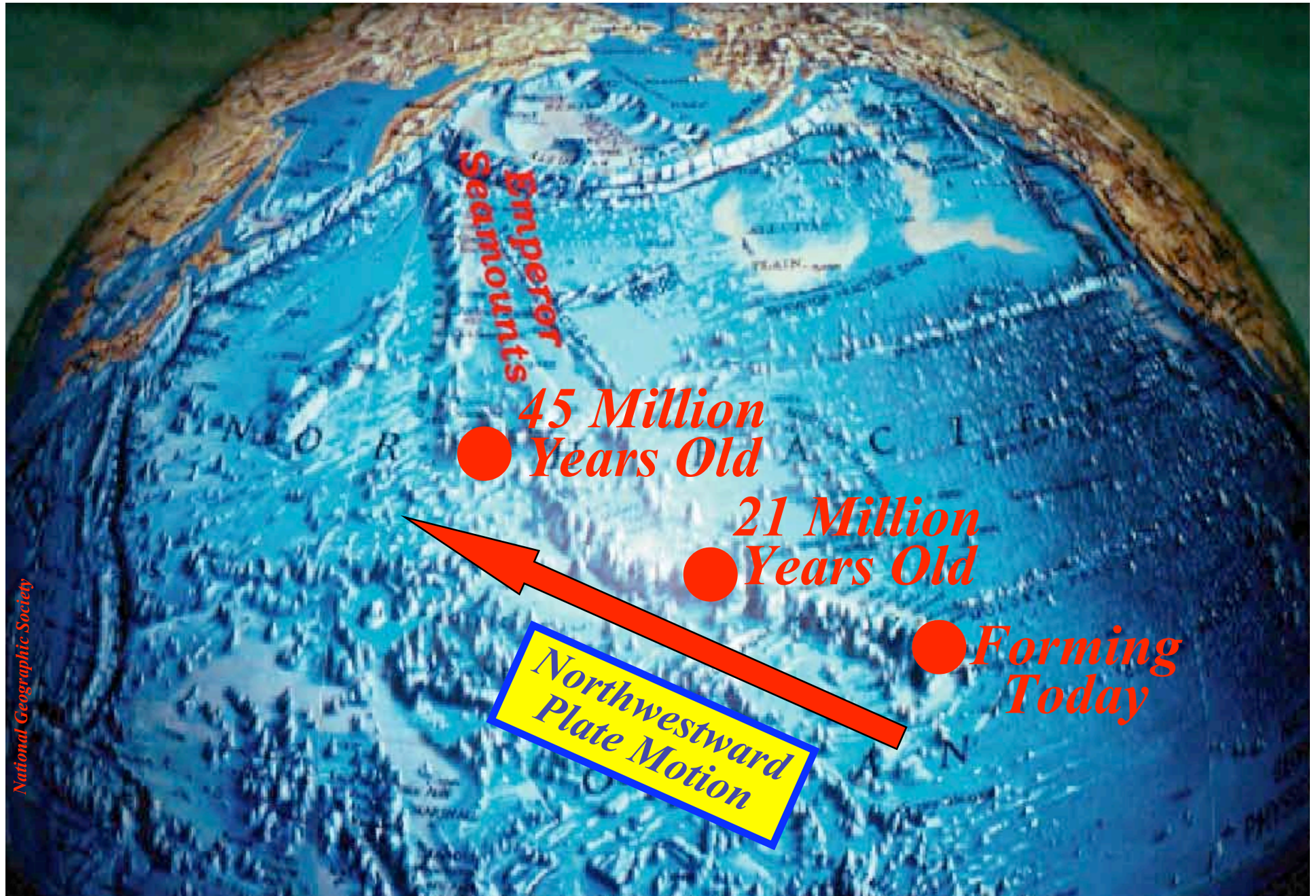


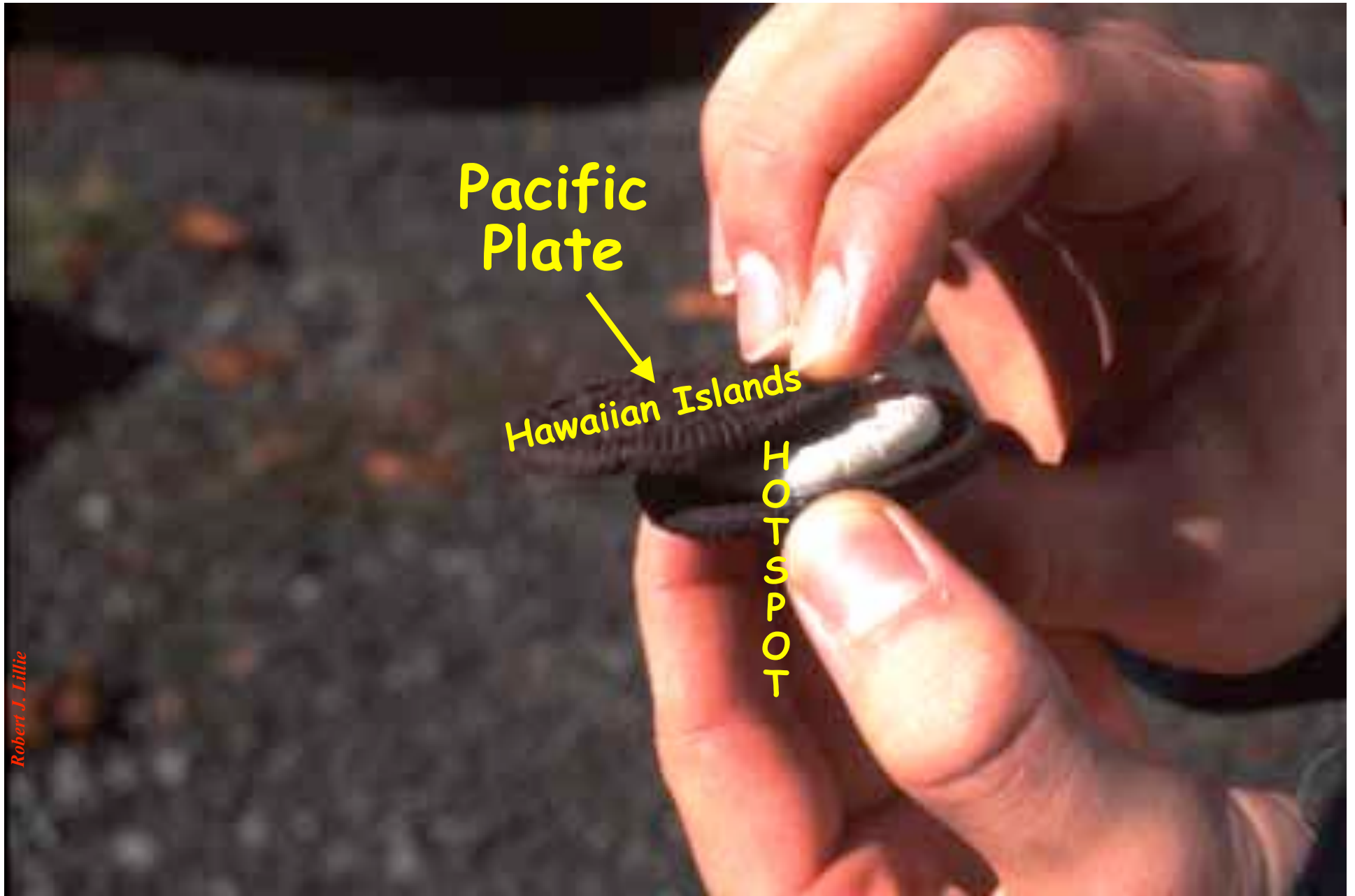
http://www.geo.utep.edu/kidd/Vol_eq_plates.html

Plate Boundaries



Hawai`i – Emperor Hotspot Track



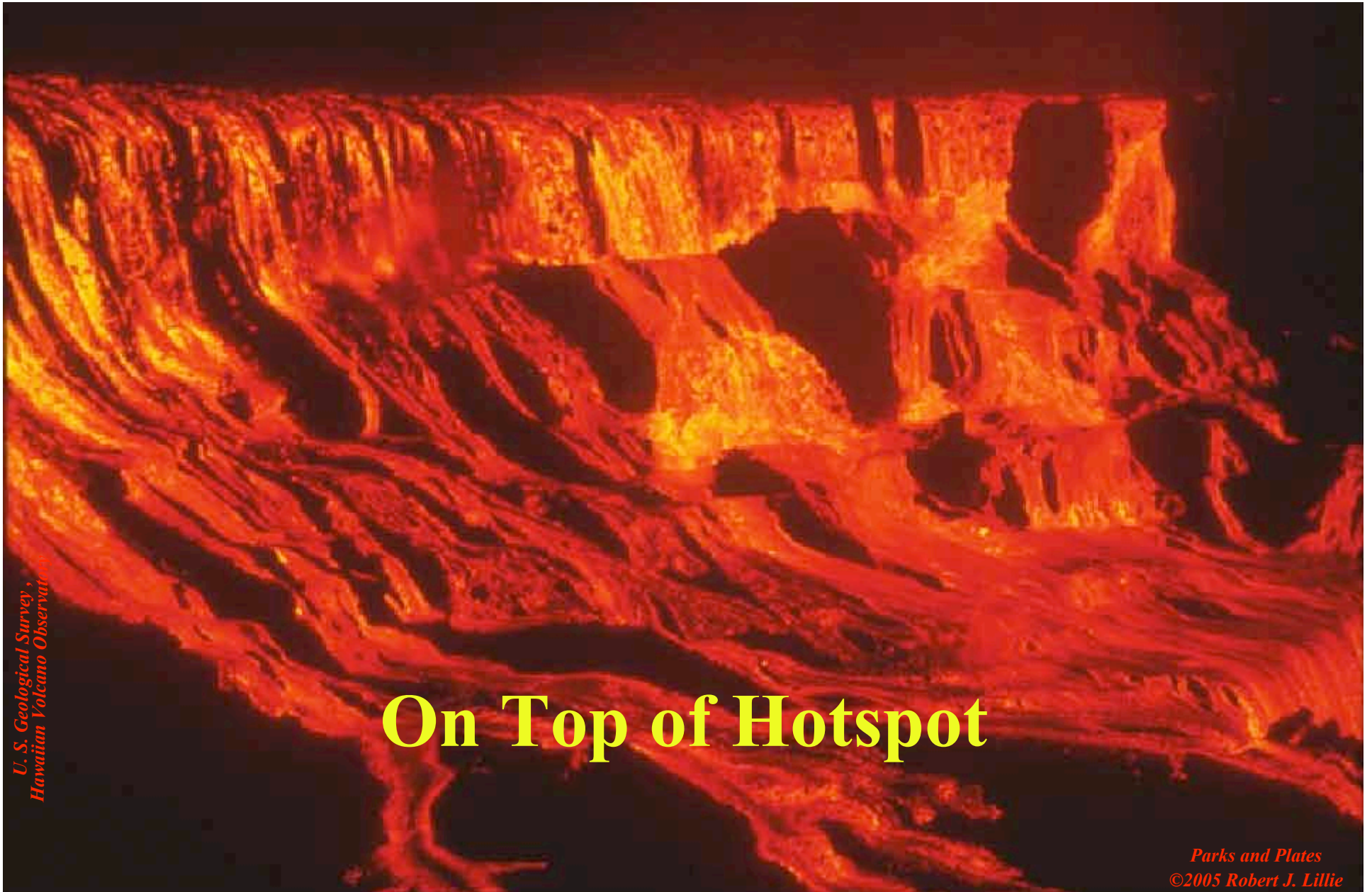


Robert J. Lillie

Pacific Plate Riding Over Hawaiian Hotspot

Parks and Plates ©2005 Robert J. Lillie

Hawai`i Volcanoes National Park, Hawai`i

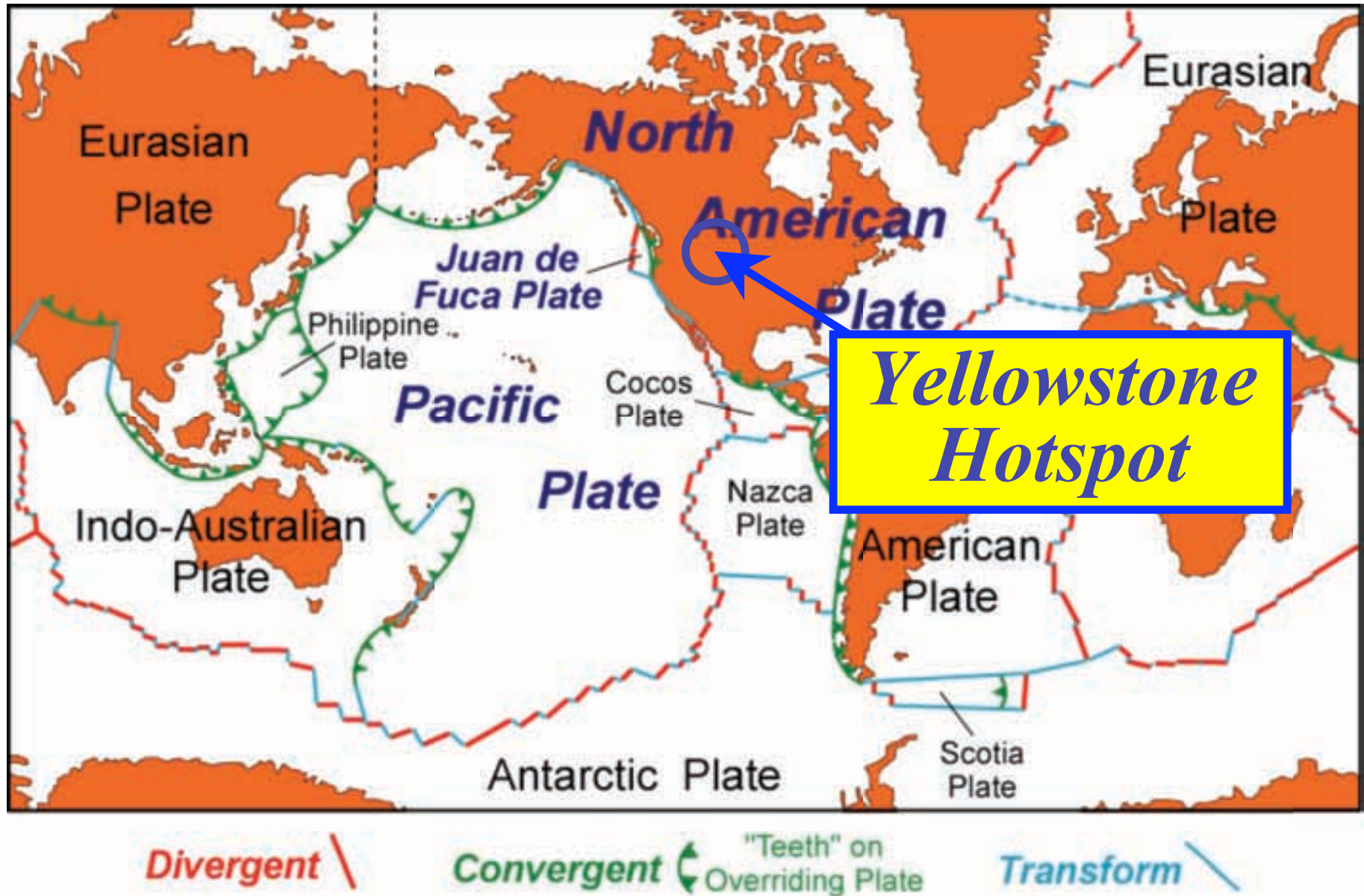


*U. S. Geological Survey,
Hawaiian Volcano Observatory*

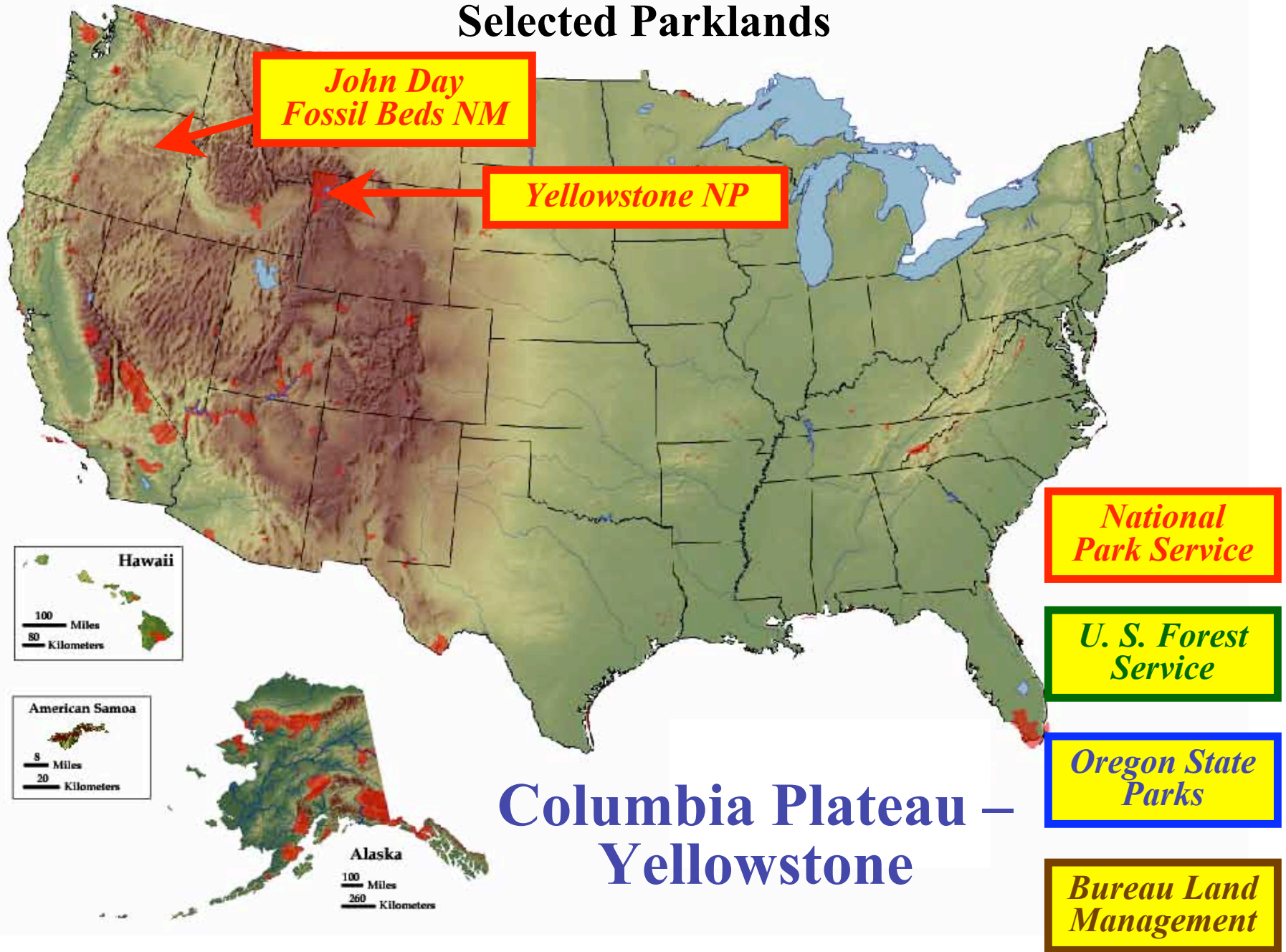
On Top of Hotspot

*Parks and Plates
©2005 Robert J. Lillie*

Plate Boundaries



Selected Parklands



*John Day
Fossil Beds NM*

Yellowstone NP

*National
Park Service*

*U. S. Forest
Service*

*Oregon State
Parks*

*Bureau Land
Management*

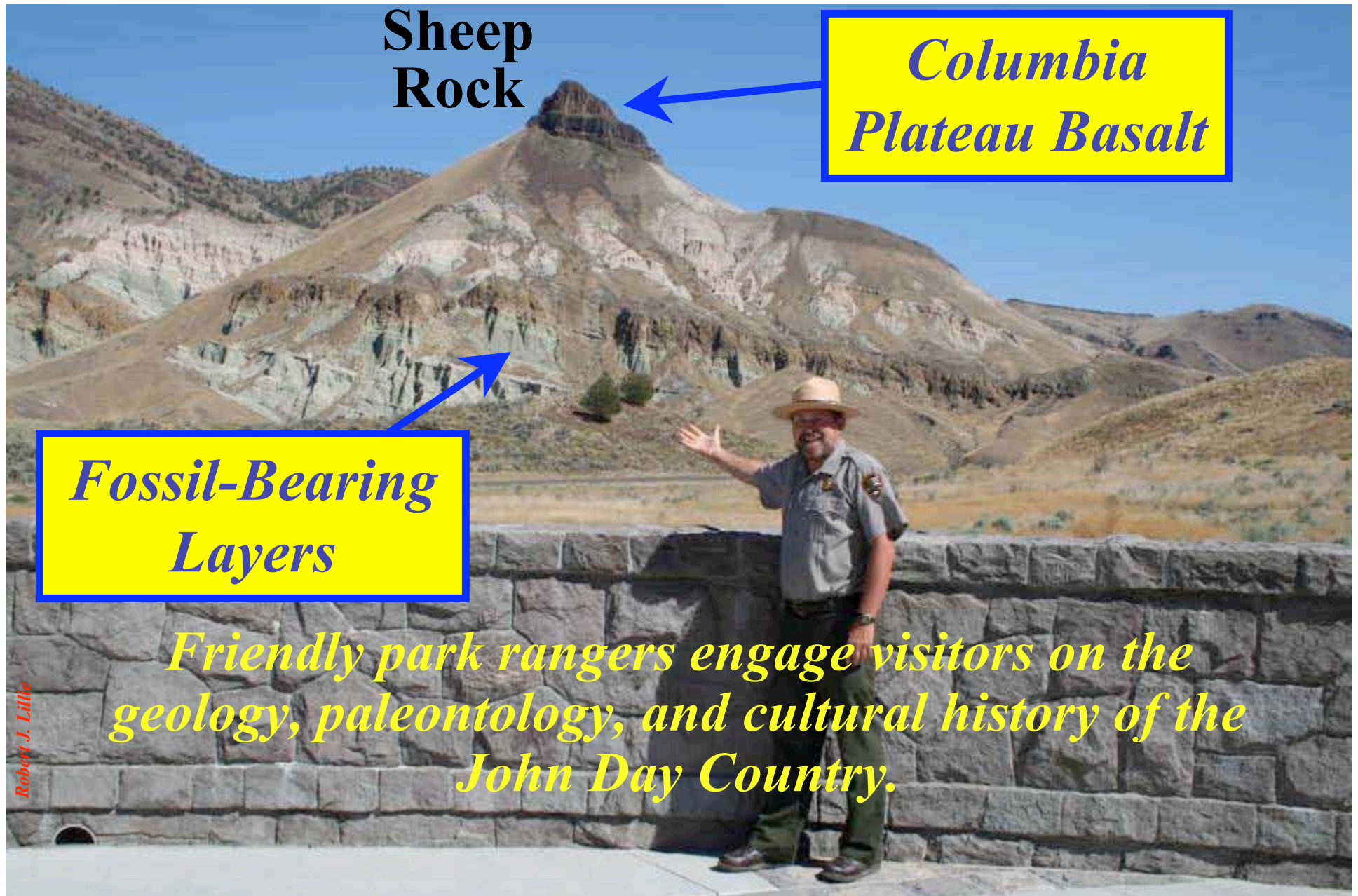
**Columbia Plateau –
Yellowstone**

Hawaii
100 Miles
80 Kilometers

American Samoa
8 Miles
20 Kilometers

Alaska
100 Miles
260 Kilometers

John Day Fossil Beds National Monument, Oregon



**Sheep
Rock**

*Columbia
Plateau Basalt*

*Fossil-Bearing
Layers*

*Friendly park rangers engage visitors on the
geology, paleontology, and cultural history of the
John Day Country.*

John Day Fossil Beds National Monument, Oregon



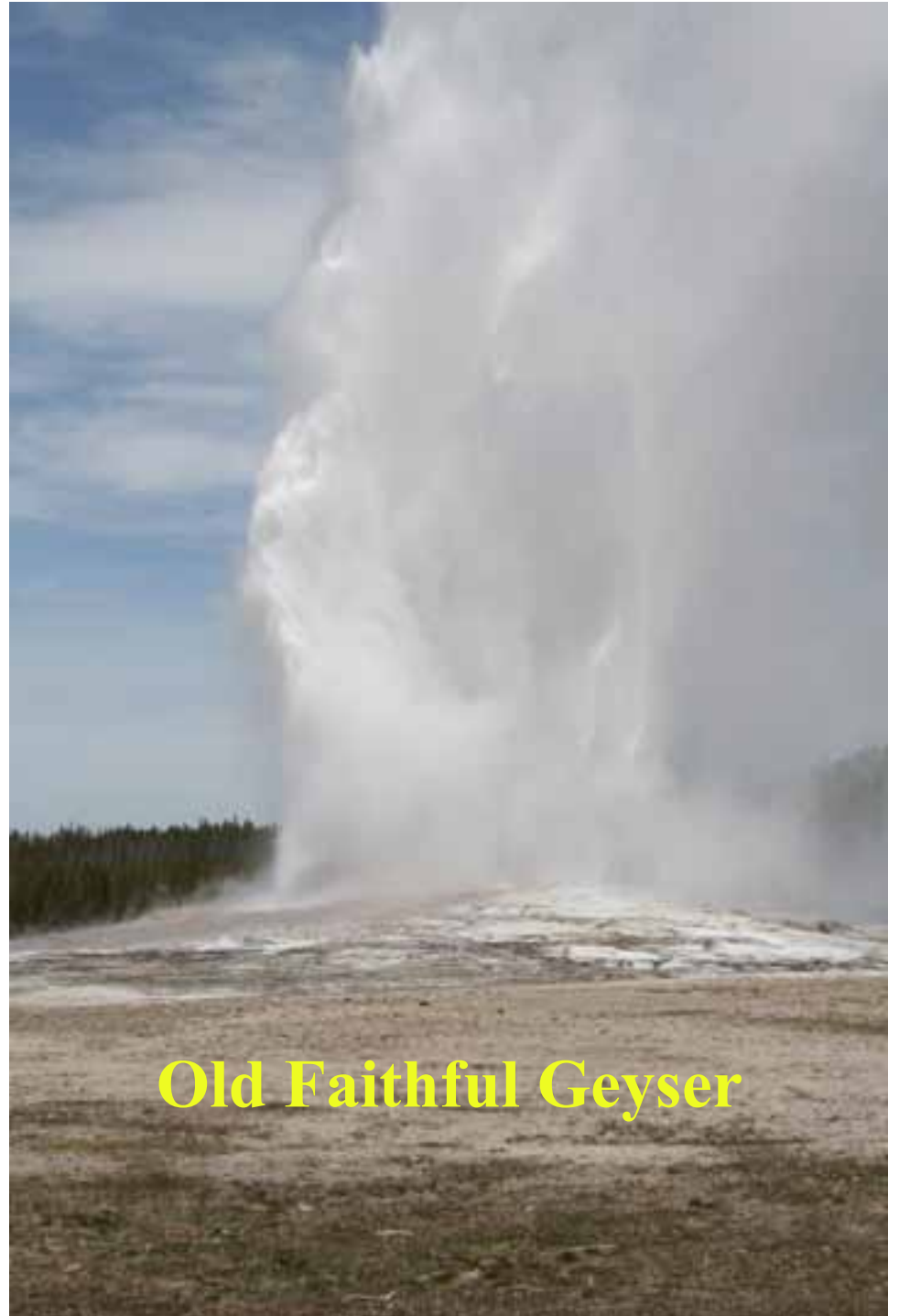
**Columbia
Plateau
Basalt**

Surfacing of Hotspot

Picture Gorge

*Yellowstone National Park,
Wyoming*

On Top of Hotspot



Old Faithful Geyser

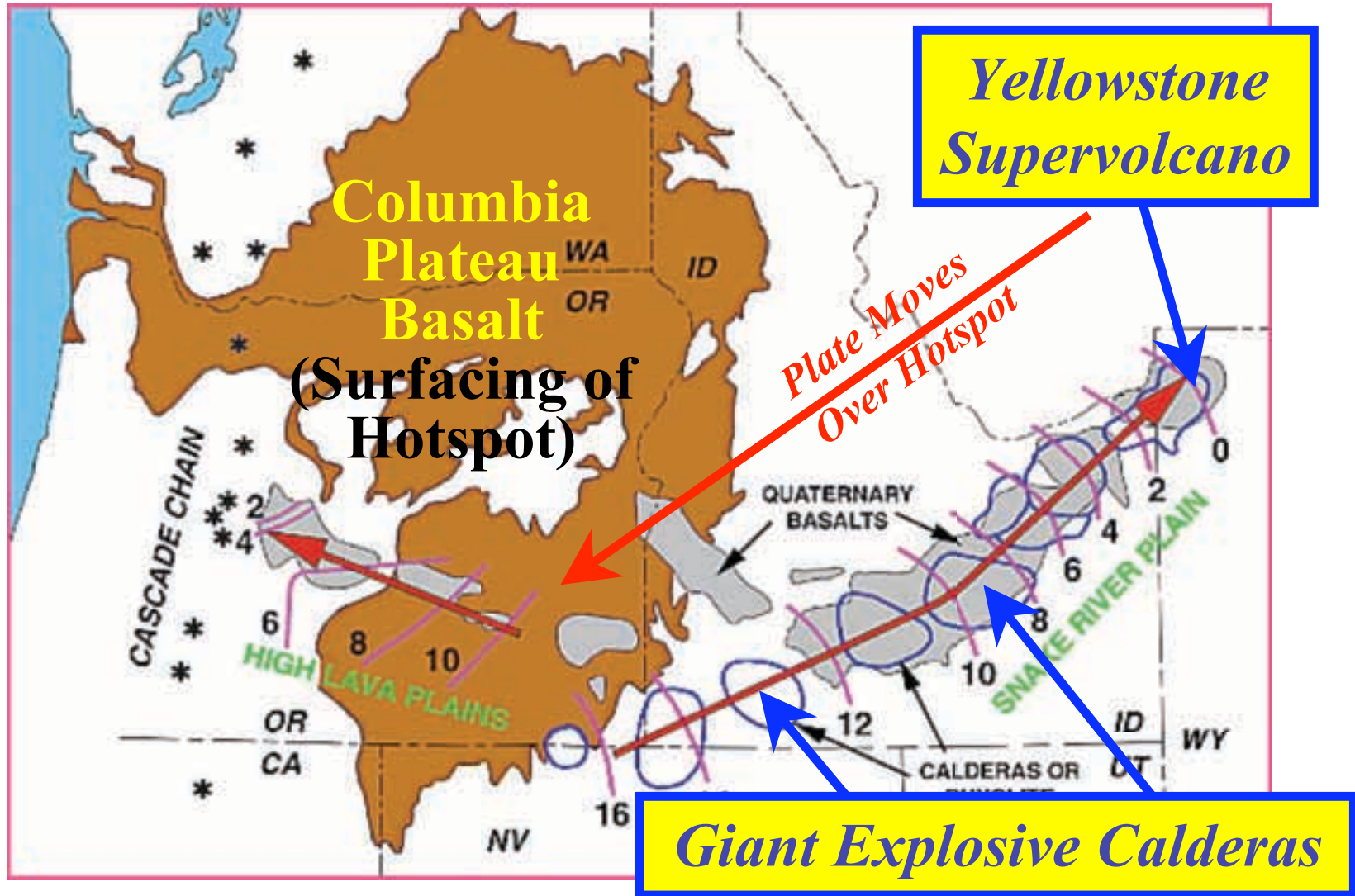
Robert J. Lillie



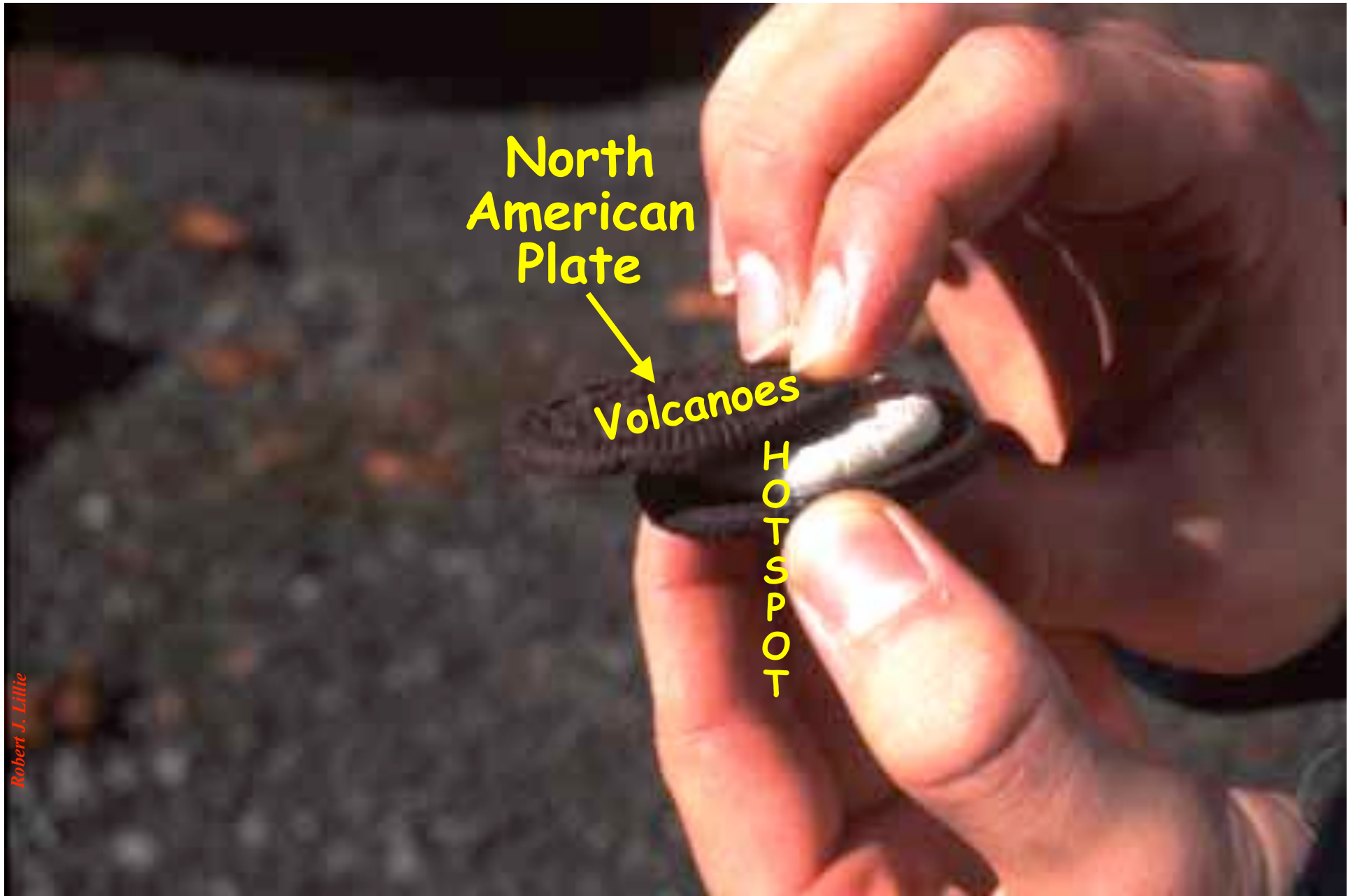
*The
Beast*

Flood Basalts and Hotspot Tracks

Numbers are age of initial lava eruptions (millions of years)



From Camp and Ross, JGR 2004



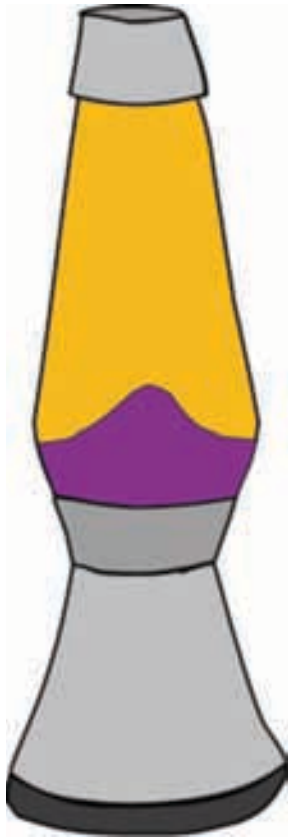
Hotspot

Lava Lamp

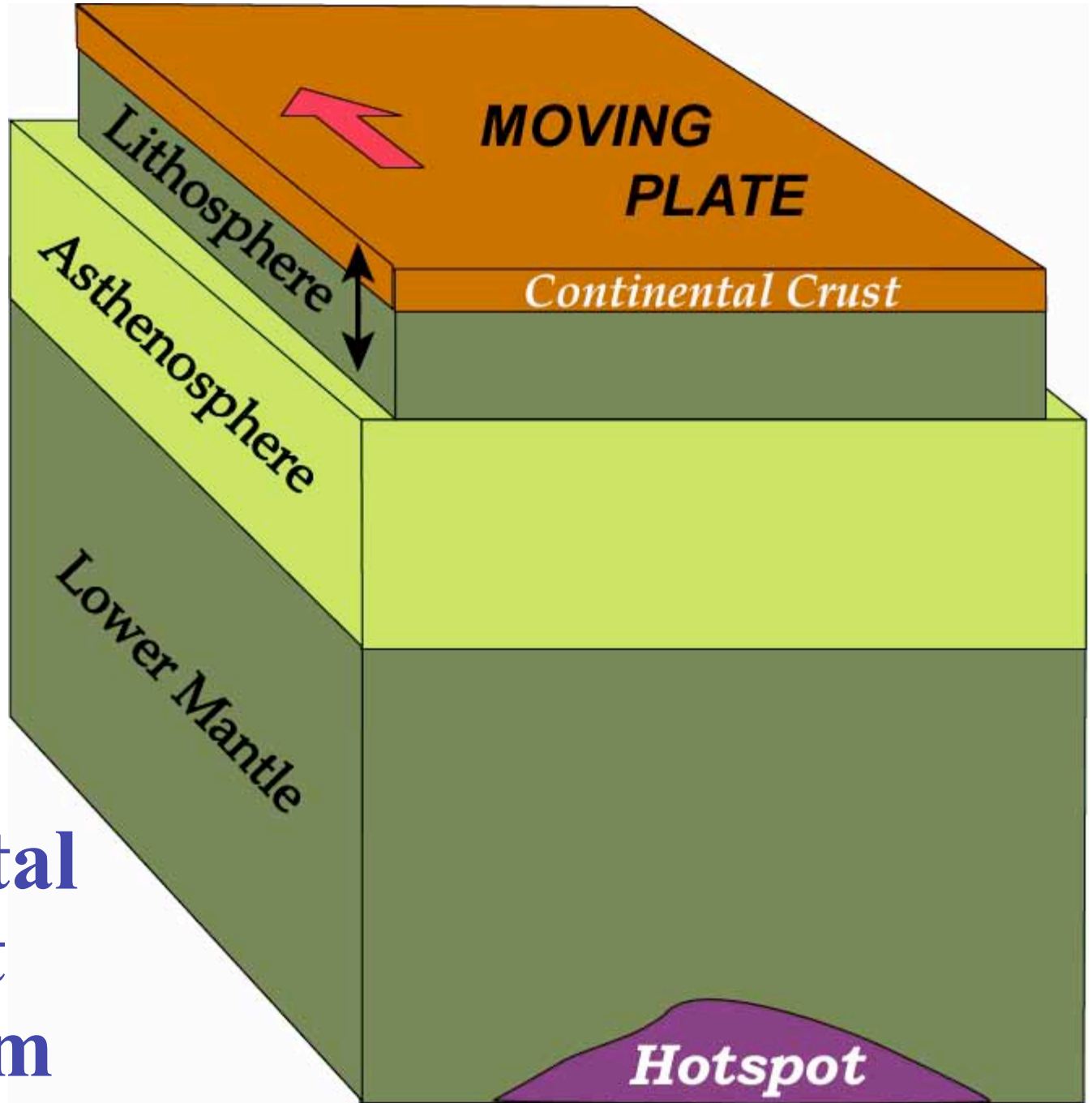


Continental Hotspot Volcanism

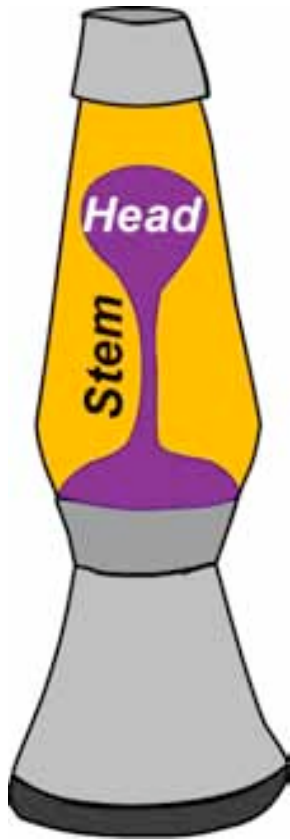
Lava Lamp



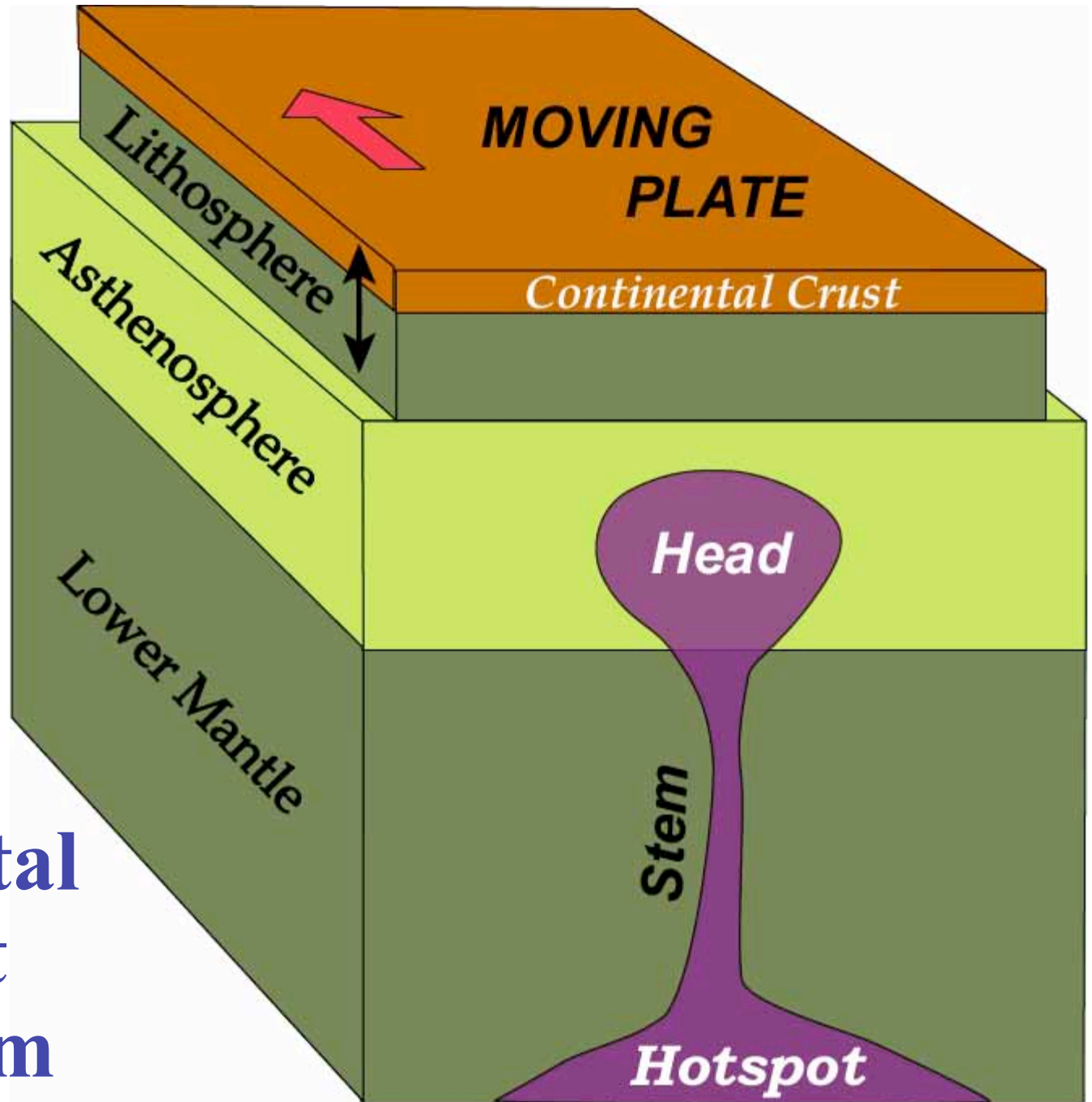
Continental Hotspot Volcanism



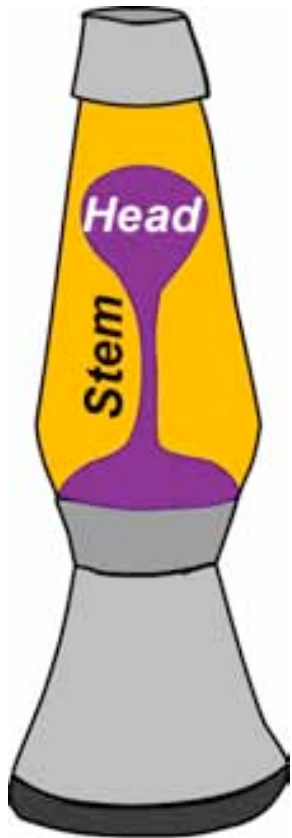
Lava Lamp



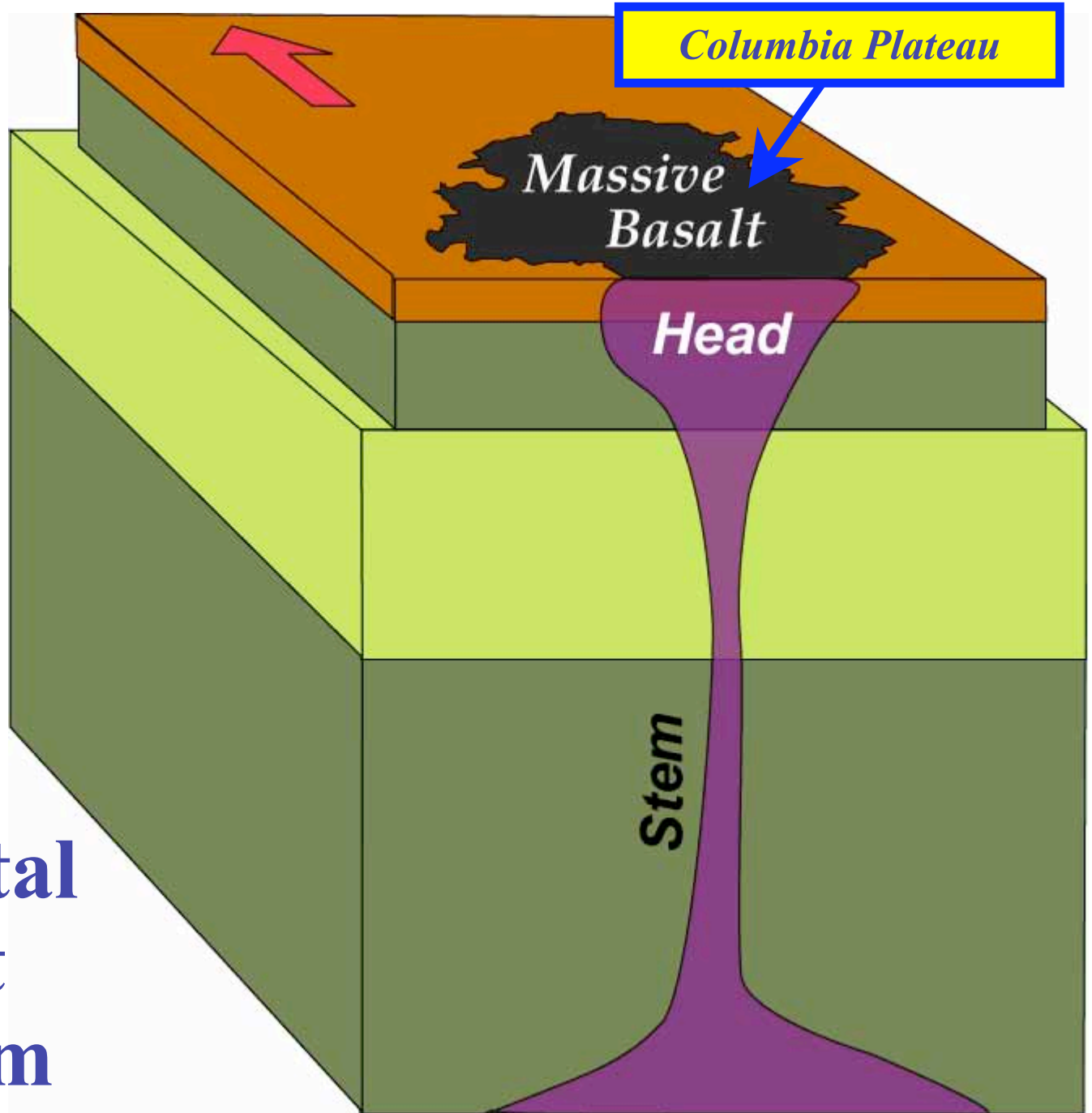
Continental Hotspot Volcanism



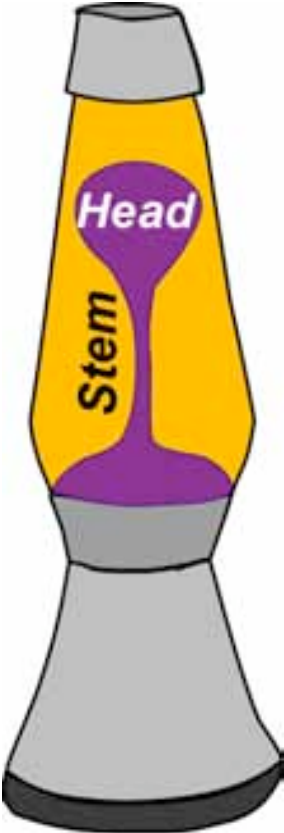
Lava Lamp



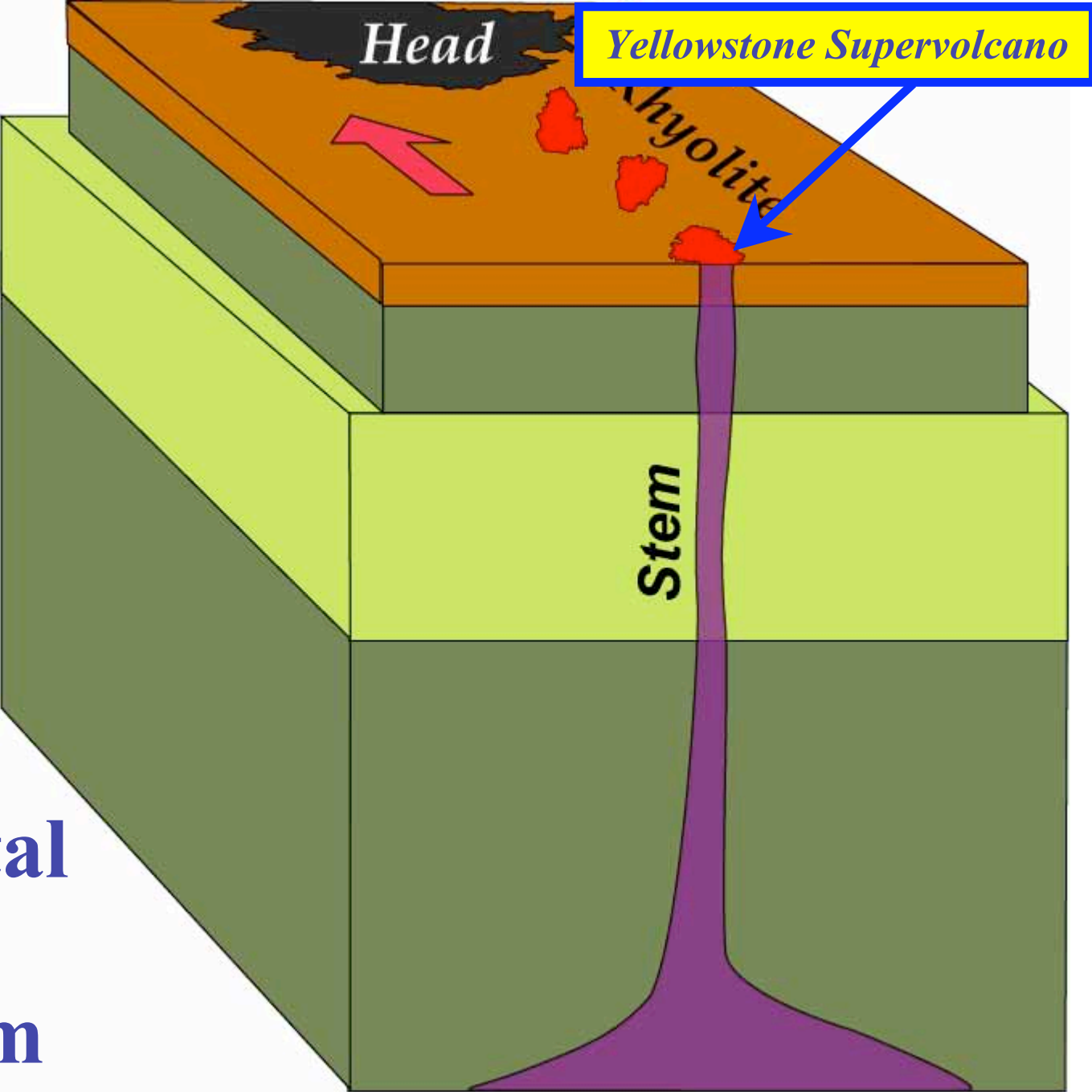
Continental Hotspot Volcanism



Lava Lamp

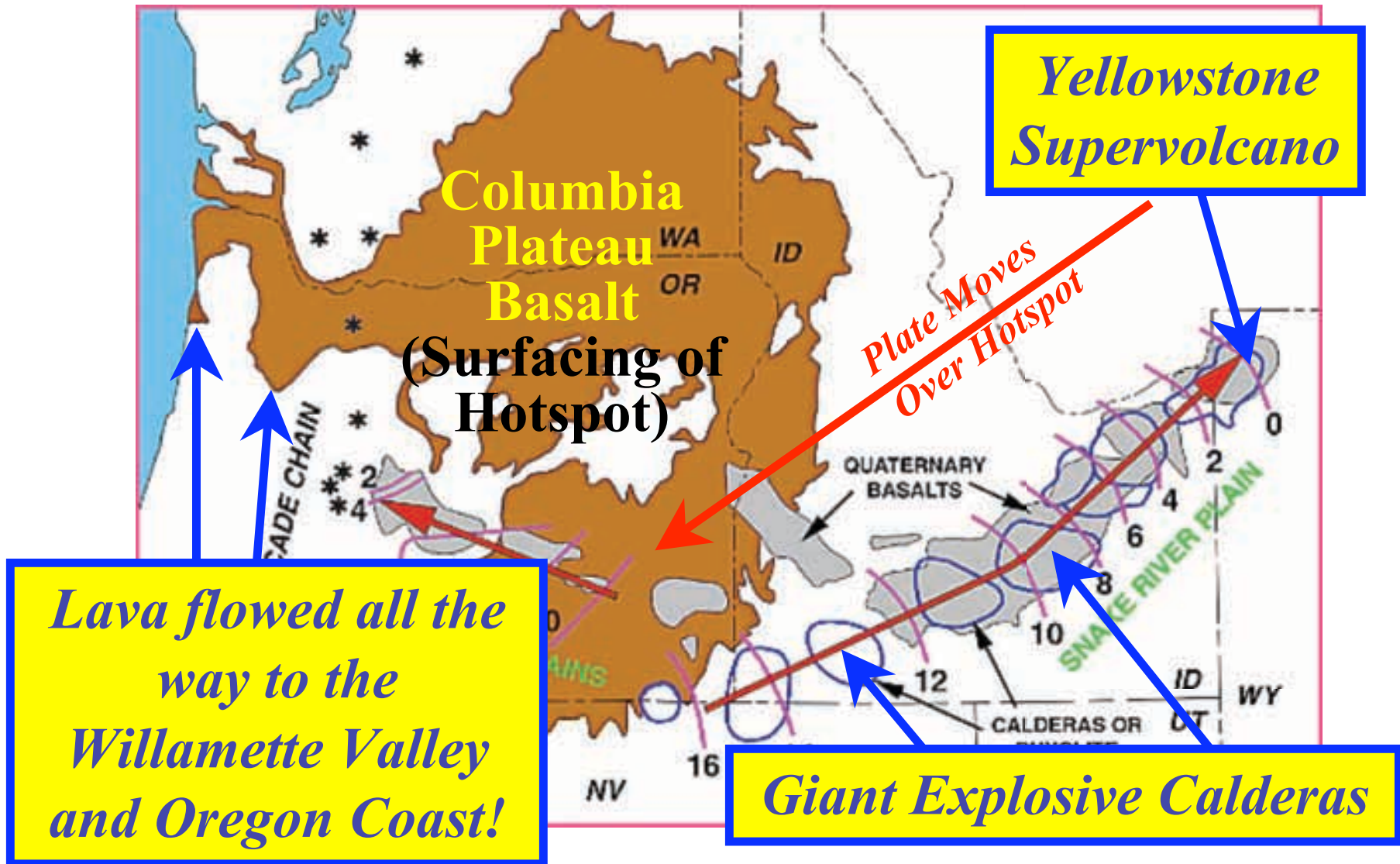


Continental Hotspot Volcanism



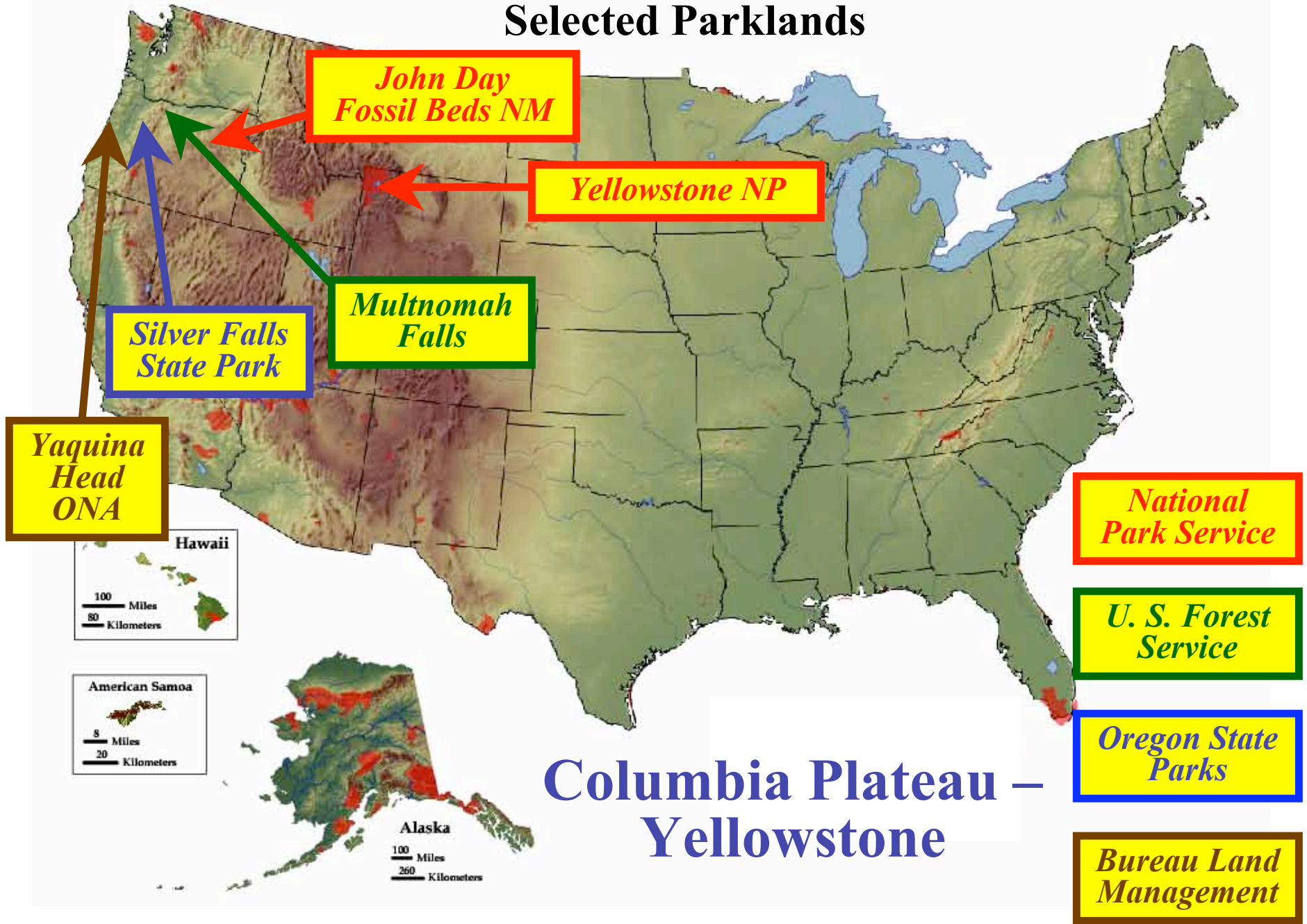
Flood Basalts and Hotspot Tracks

Numbers are age of initial lava eruptions (millions of years)



From Camp and Ross, JGR 2004

Selected Parklands



*John Day
Fossil Beds NM*

Yellowstone NP

*Multnomah
Falls*

*Silver Falls
State Park*

*Yaquina
Head
ONA*

*National
Park Service*

*U. S. Forest
Service*

*Oregon State
Parks*

*Bureau Land
Management*

Hawaii
100 Miles
80 Kilometers

American Samoa
8 Miles
20 Kilometers

Alaska
100 Miles
260 Kilometers

**Columbia Plateau –
Yellowstone**



**Many of Oregon's
majestic waterfalls flow
over resistant
Columbia Plateau
Basalt**

***Columbia Gorge National
Scenic Area,
Oregon/Washington***

U. S. Forest Service



**Many of Oregon's
majestic waterfalls flow
over resistant
Columbia Plateau
Basalt**



***Silver Falls State Park,
Oregon***

South Falls

Robert J. Lillie

Yaquina Head Outstanding Natural Area, Oregon

**Many of Oregon's coastal headlands are also resistant
Columbia Plateau Basalt**





**Columbia Plateau Basalt
Continental Hotspot Volcanism
~ 15 Million Years Old (Middle Miocene)**

Cape Lookout

Robert J. Little

Cape Meares Scenic Viewpoint, Oregon

**Columbia Plateau Basalt
Continental Hotspot Volcanism
~ 15 Million Years Old (Middle Miocene)**

Cape Meares

Robert J. Little

Cape Lookout State Park, Oregon



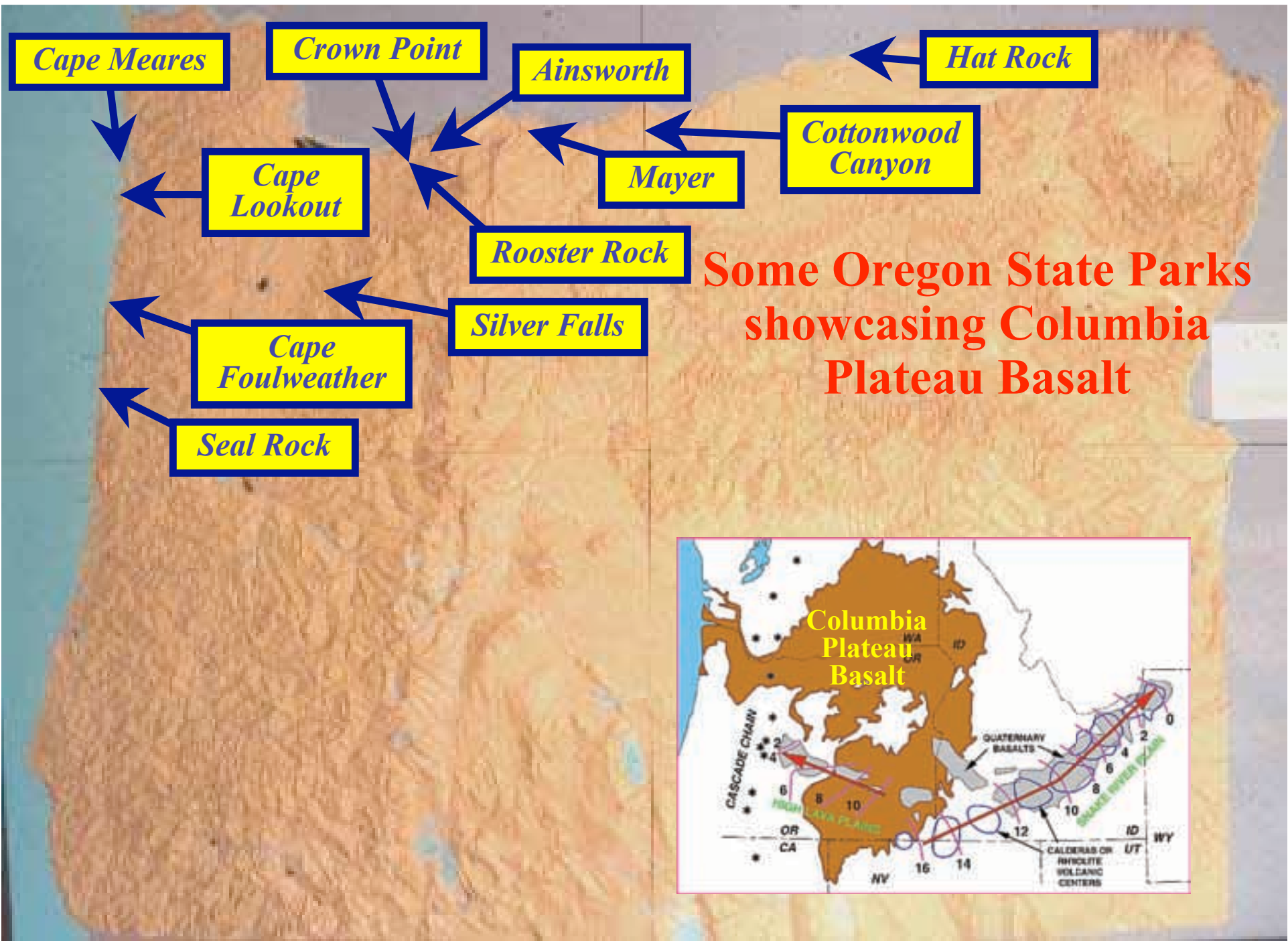
Devils Punch Bowl State Natural Area, Oregon



Columbia Plateau Basalt

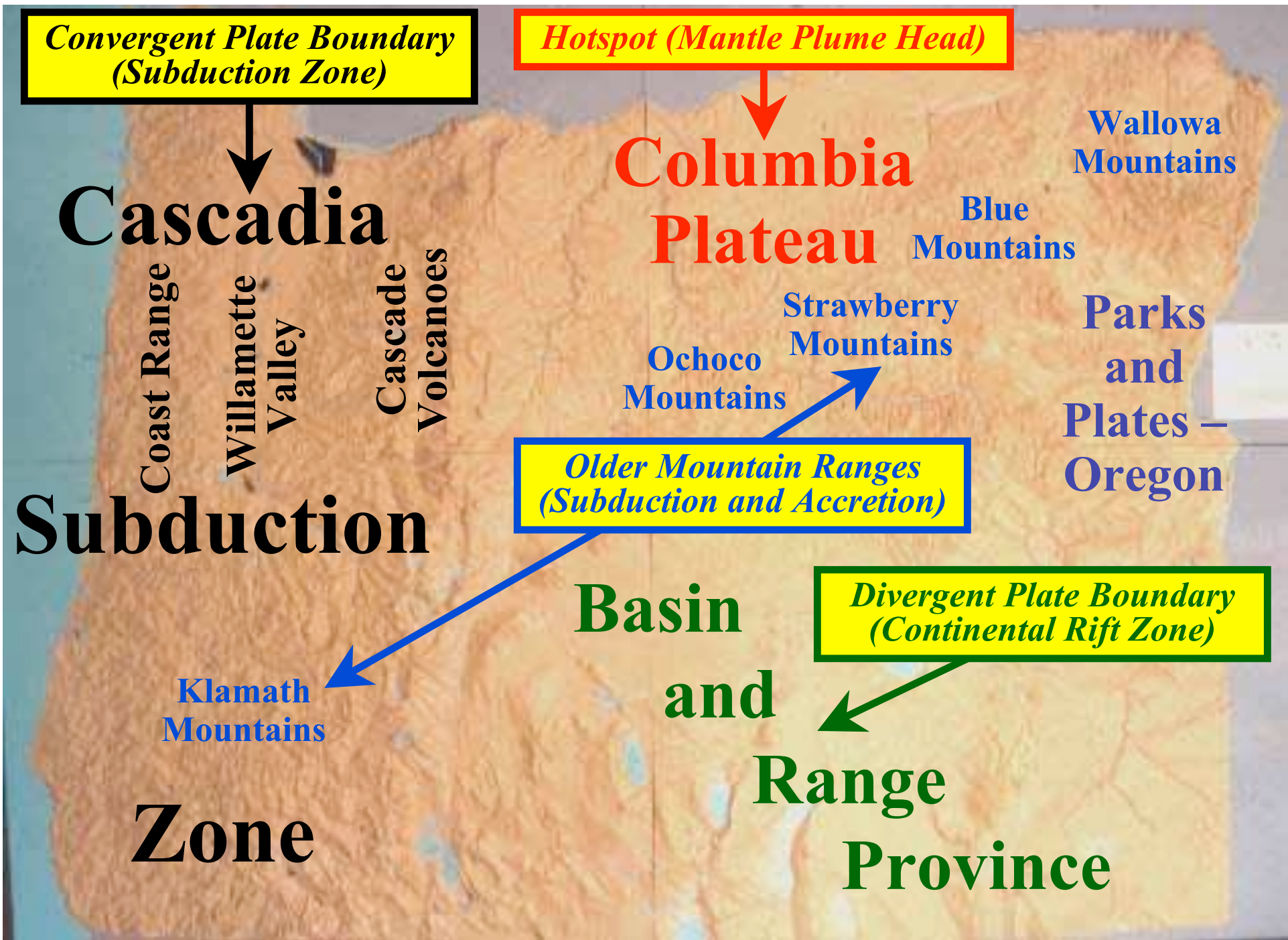
Oregon Parks and Recreation Department

Cottonwood Canyon State Park, Oregon



Some Oregon State Parks showcasing Columbia Plateau Basalt





Wallowa Mountains



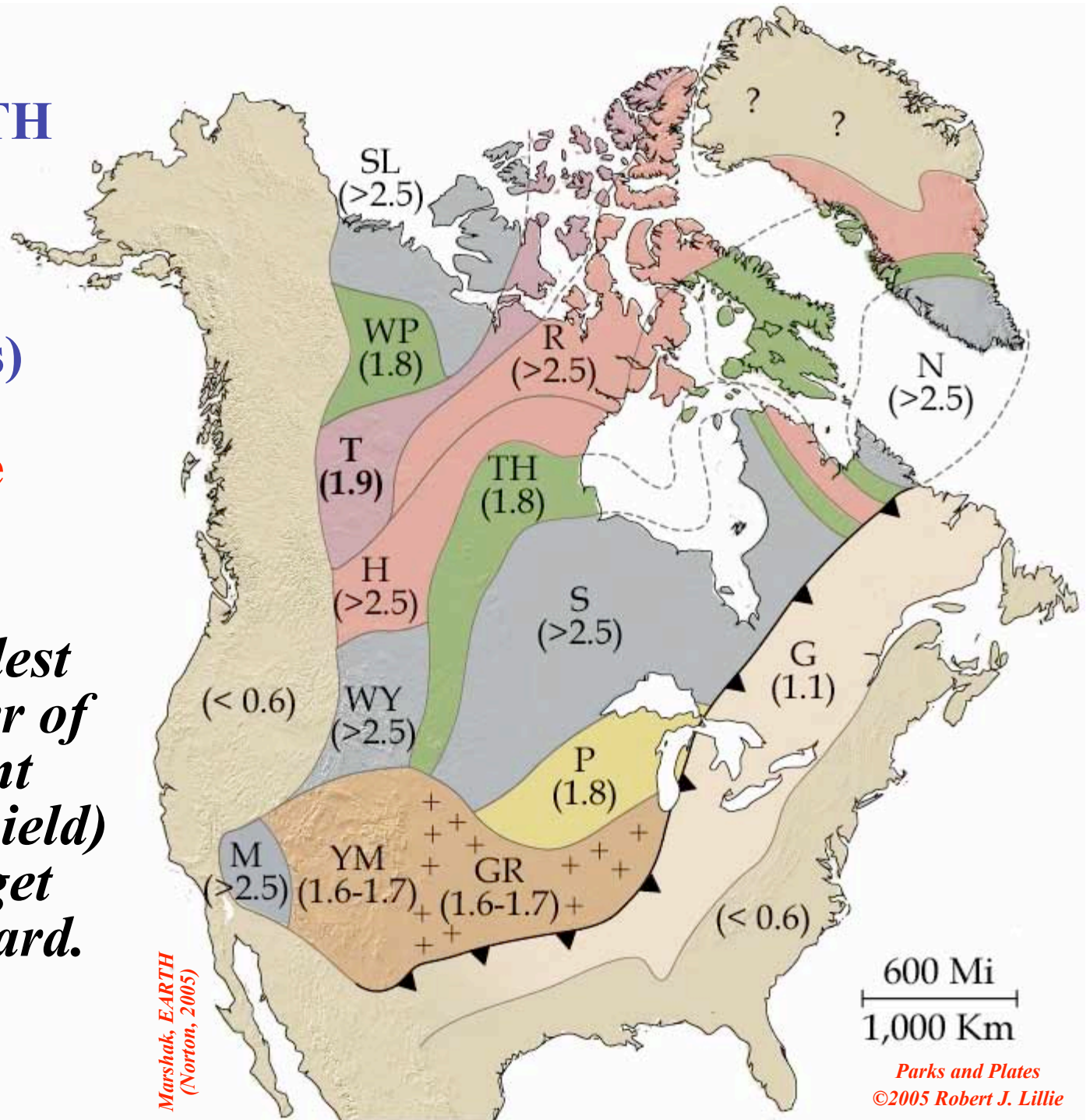
Oregon Parks and Recreation Department

Wetemlaykin State Heritage Site, Oregon

AGE OF NORTH AMERICAN BASEMENT ROCKS (Billions Years)

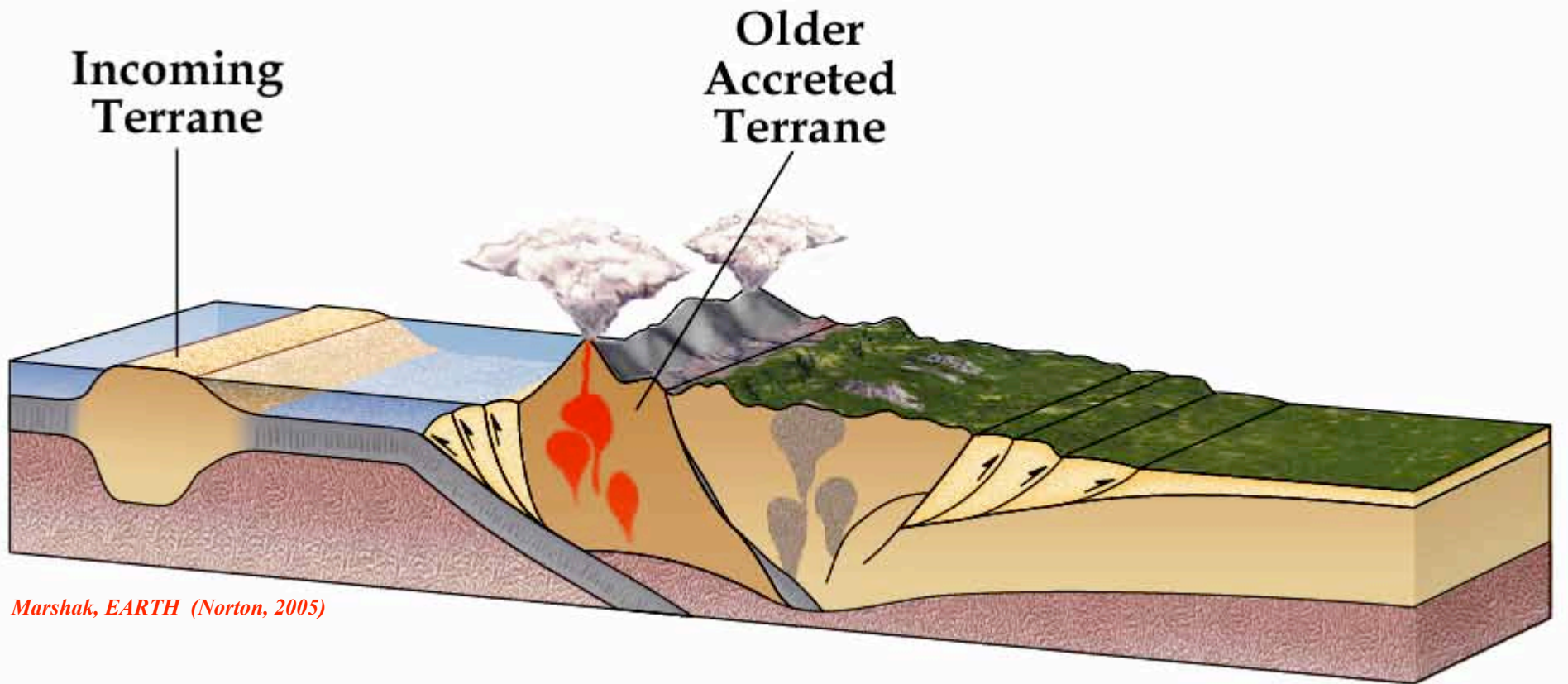
What's the Pattern?

Rocks are oldest near the center of the continent (continental shield) and tend to get younger outward.



Terrane Accretion

A TERRANE consists of crust that is too thick and buoyant to subduct. The continent grows outward as terranes come crashing in.



Marshak, EARTH (Norton, 2005)

Safeway Terrane Accretion ☺

**Forth
Terrane**

Third Terrane

**Second
Terrane**

Ocean Plate

First Terrane

**North American
Plate**

**Second
Terrane**

First Terrane



Ocean Plate



Ocean Plate

Third Terrane



Robert J. Lillie

Ocean Plate

**Fourth
Terrane**



Ocean Plate



Ocean Plate

Fourth Terrane

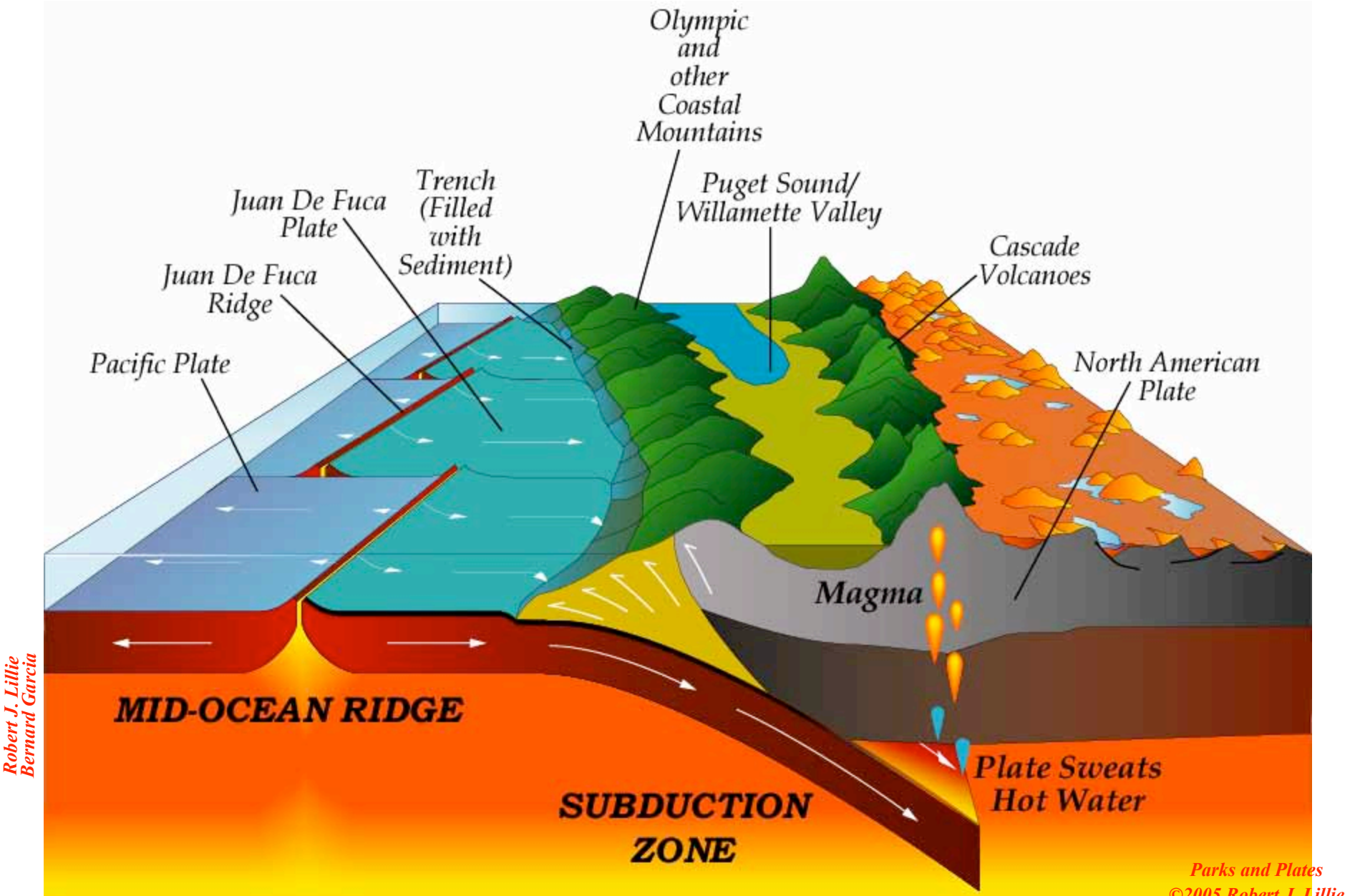
Third Terrane

Second Terrane

First Terrane

North American plate

The Cascadia Subduction Zone is just the latest episode of the Pacific Northwest building outward by Terrane Accretion.

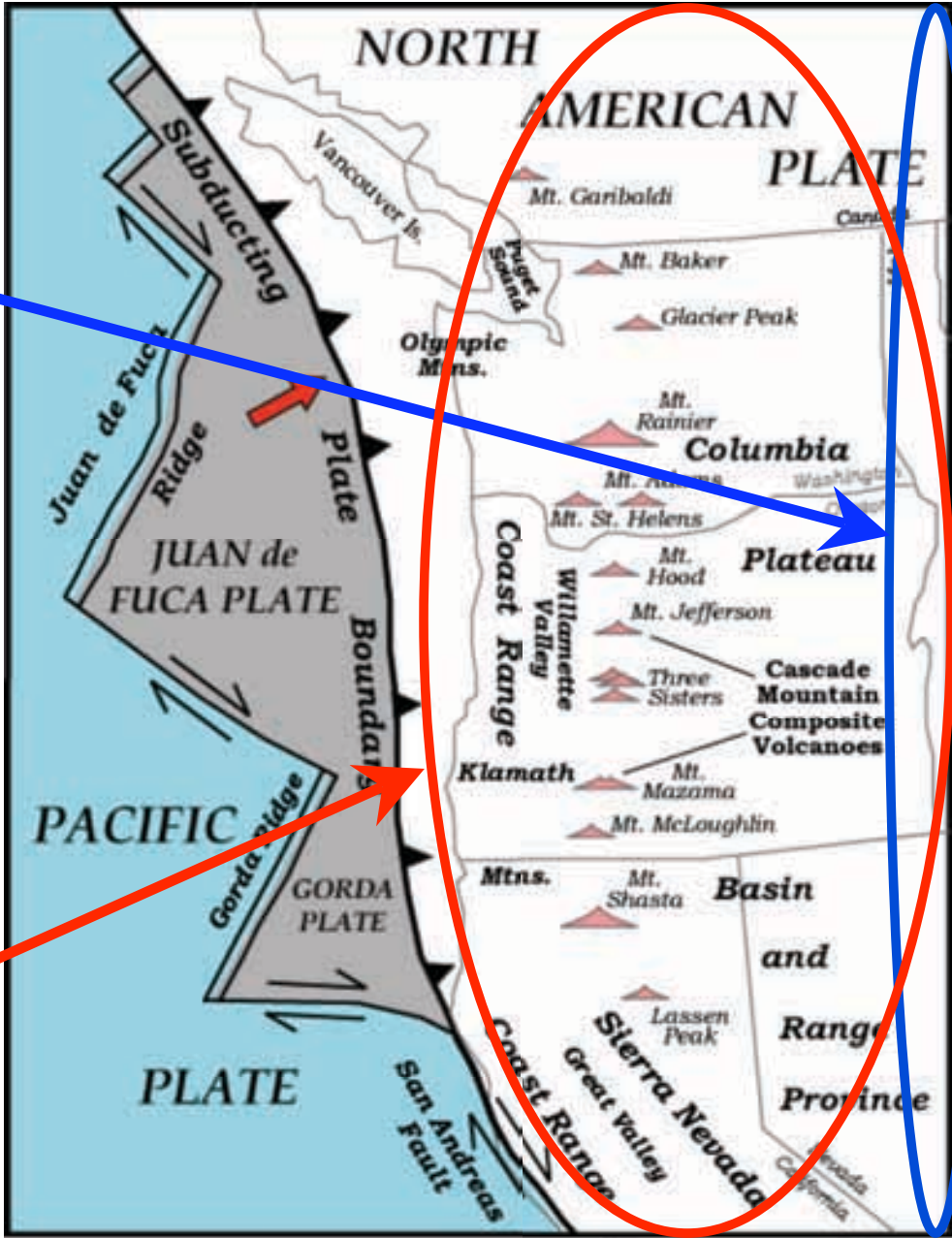


Robert J. Lillie
Bernard Garcia

*Coastline
150 Million
Years Ago*

*Most of Oregon and
Washington has been
added to the edge of the
continent in the past 150
million years*

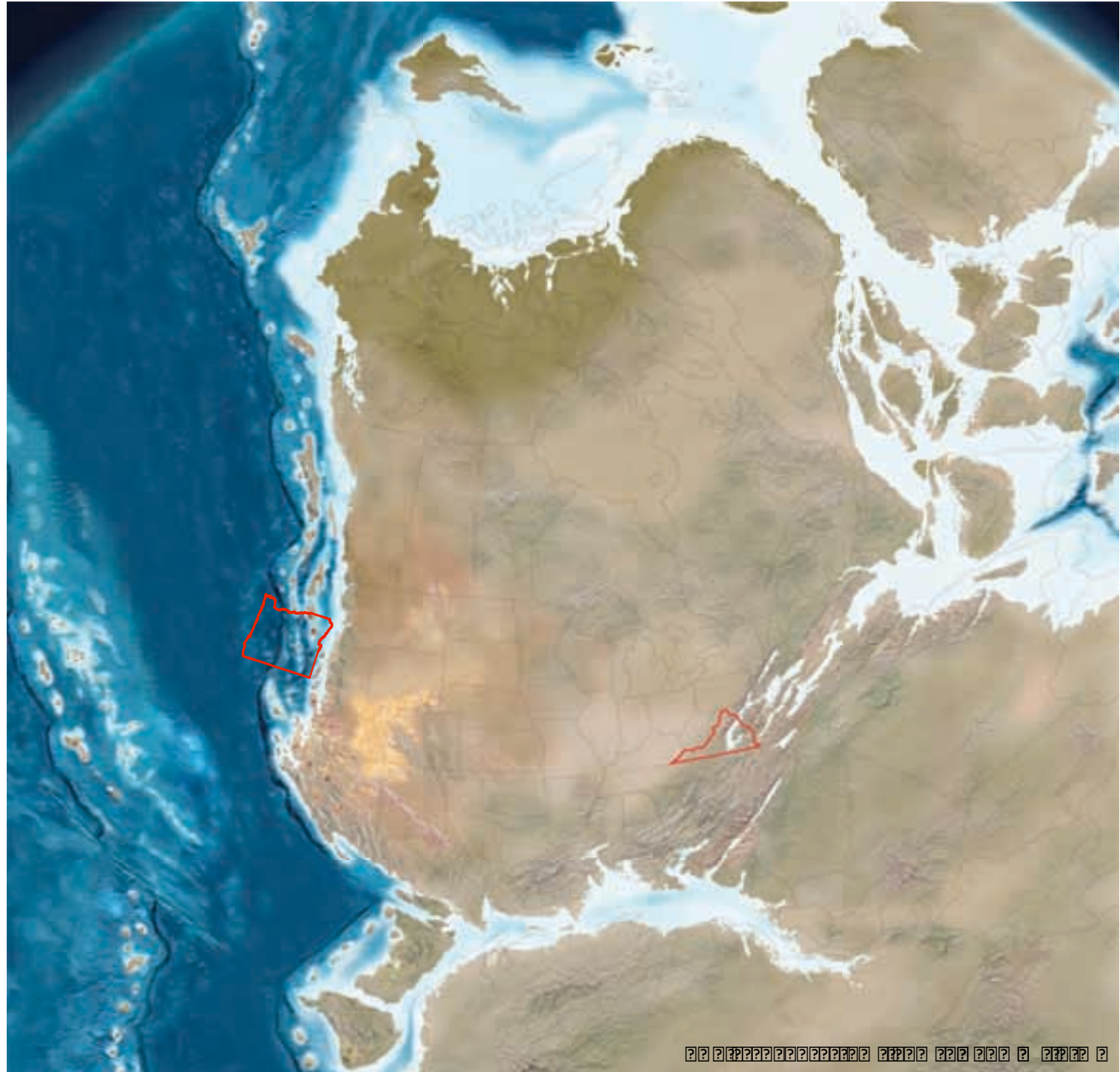
*Material added
since then by
Subduction and
Terrane Accretion*



Jurassic

195
Million Years Ago

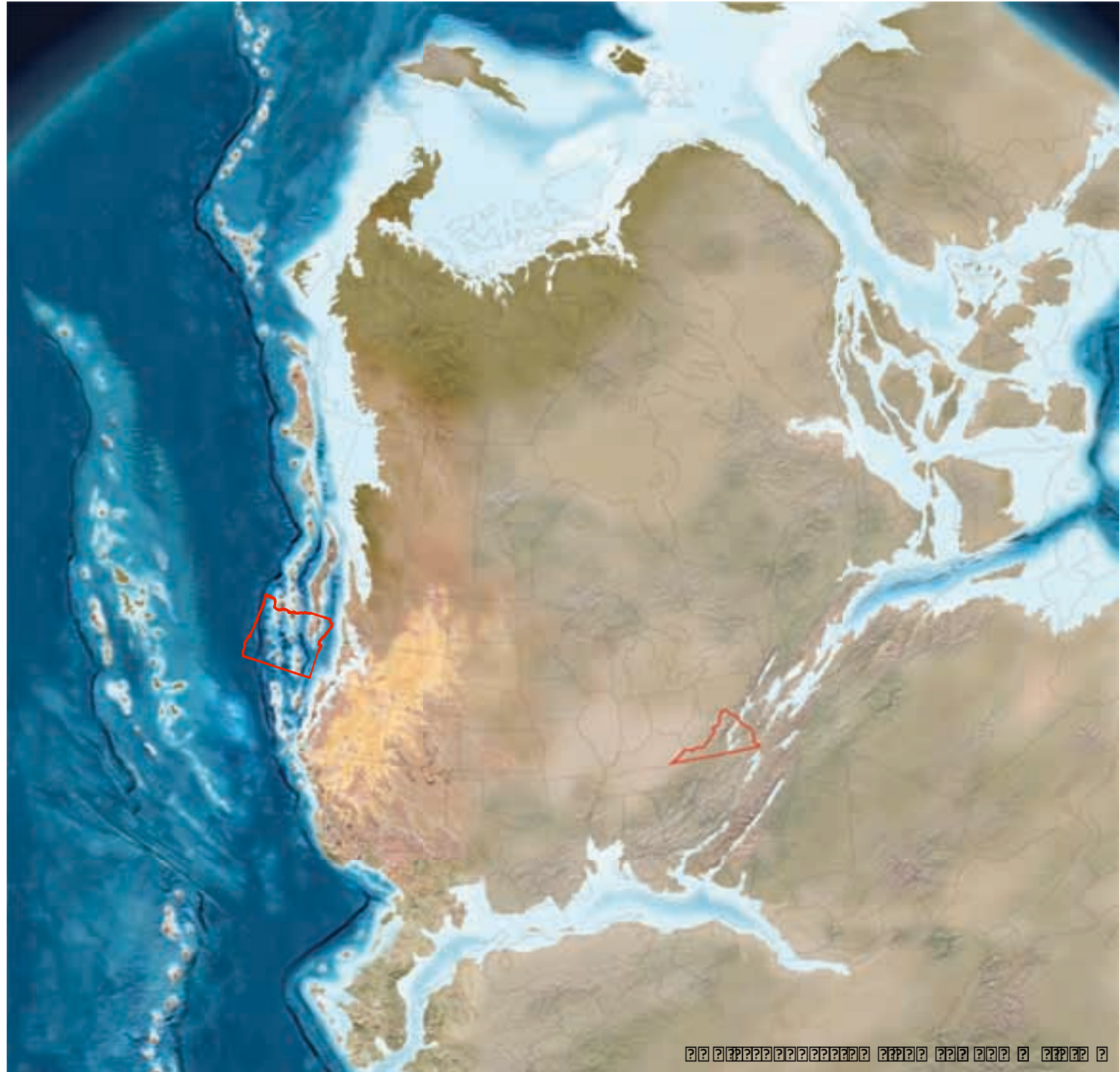
Ron Blakey
Northern Arizona
University



Jurassic

180
Million Years Ago

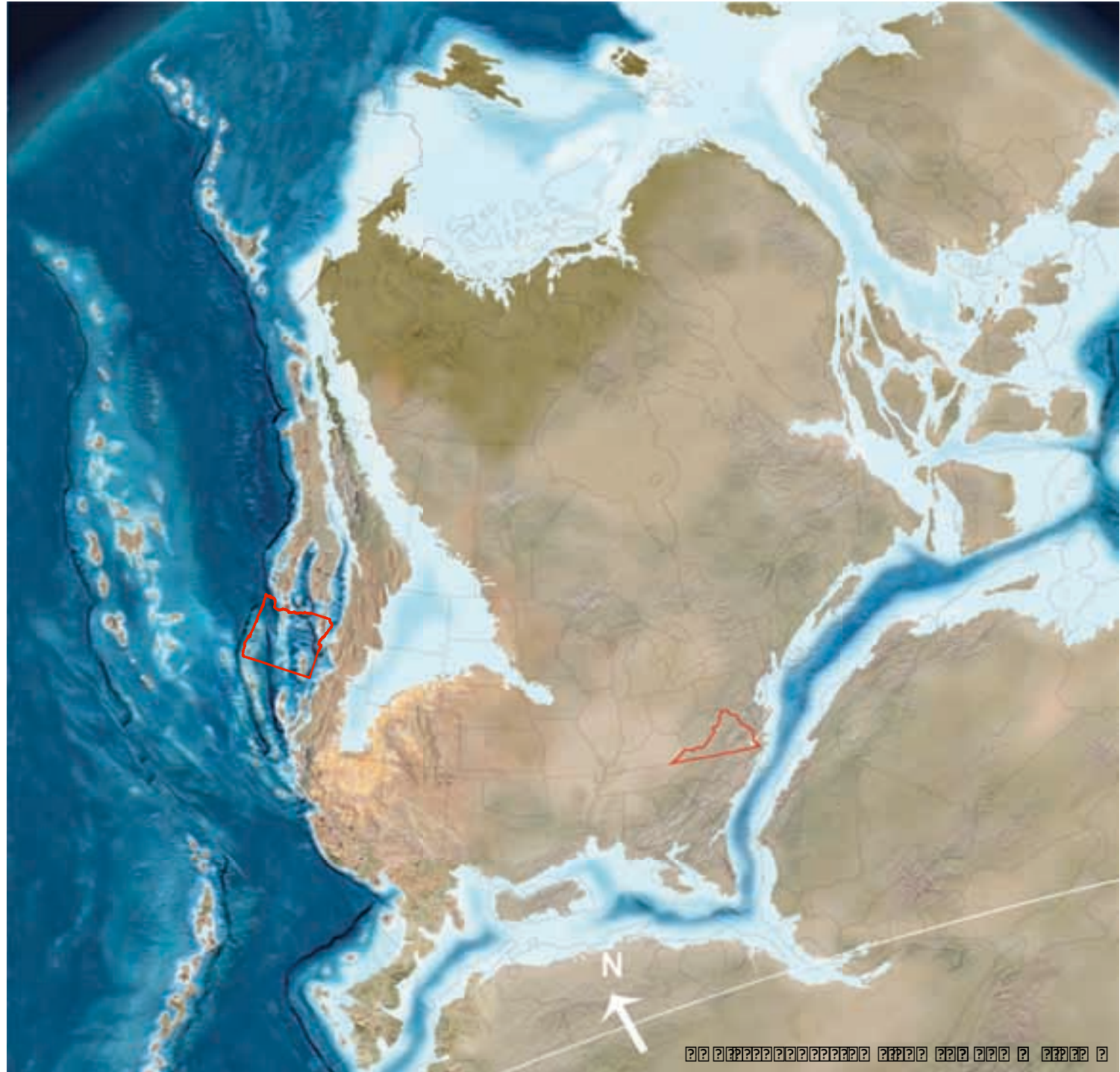
Ron Blakey
Northern Arizona
University



Jurassic

170
Million Years Ago

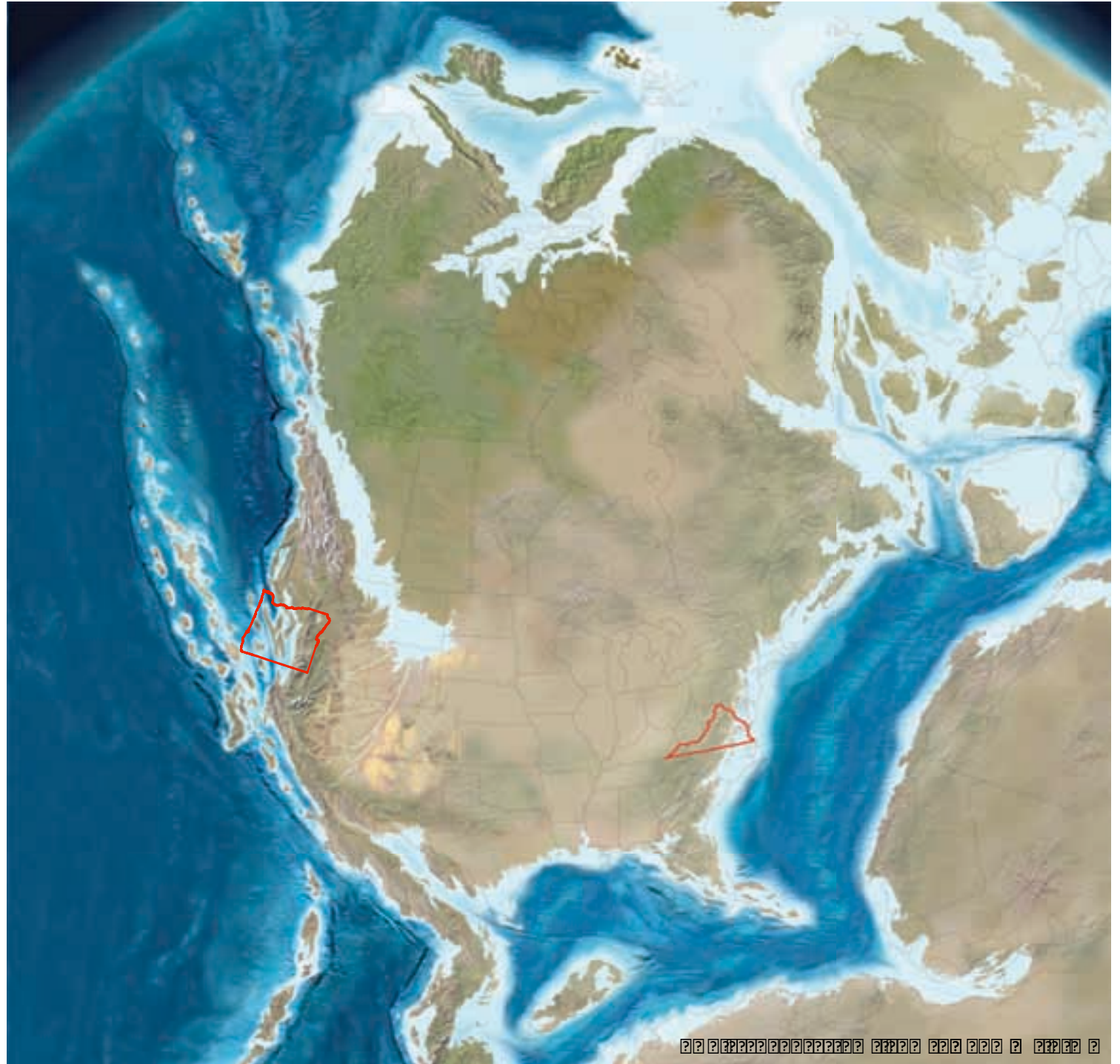
Ron Blakey
Northern Arizona
University



Jurassic

150
Million Years Ago

Ron Blakey
Northern Arizona
University



Cretaceous

**140
Million Years Ago**

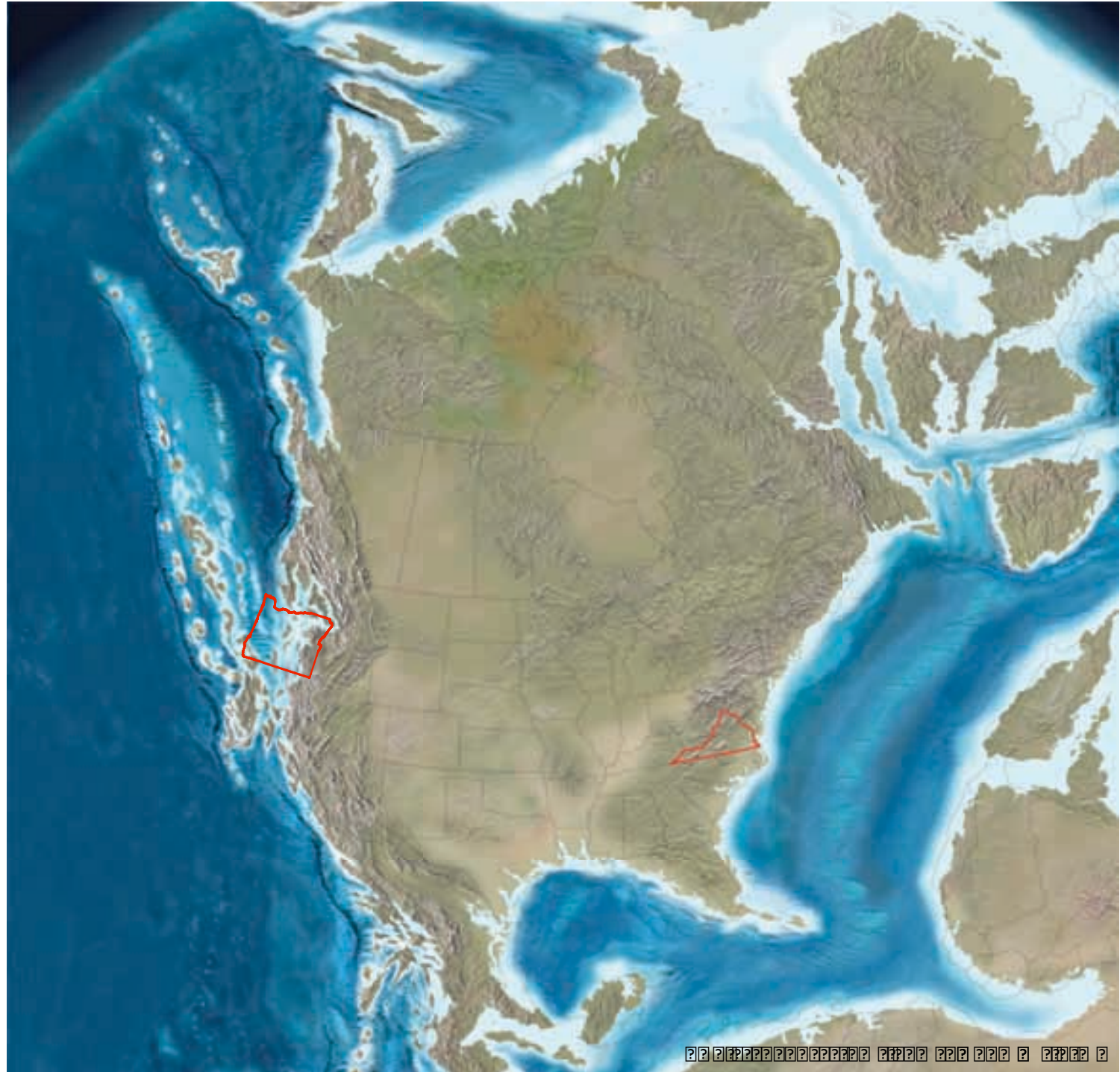
**Ron Blakey
Northern Arizona
University**



Cretaceous

130
Million Years Ago

Ron Blakey
Northern Arizona
University



Cretaceous

115
Million Years Ago

Ron Blakey
Northern Arizona
University



Eocene

50
Million Years Ago

Ron Blakey
Northern Arizona
University



Eocene

40

Million Years Ago

**Ron Blakey
Northern Arizona
University**



Oligocene

25

Million Years Ago



Ron Blakey
Northern Arizona
University

Miocene

15
Million Years Ago

Ron Blakey
Northern Arizona
University



Miocene

8

Million Years Ago

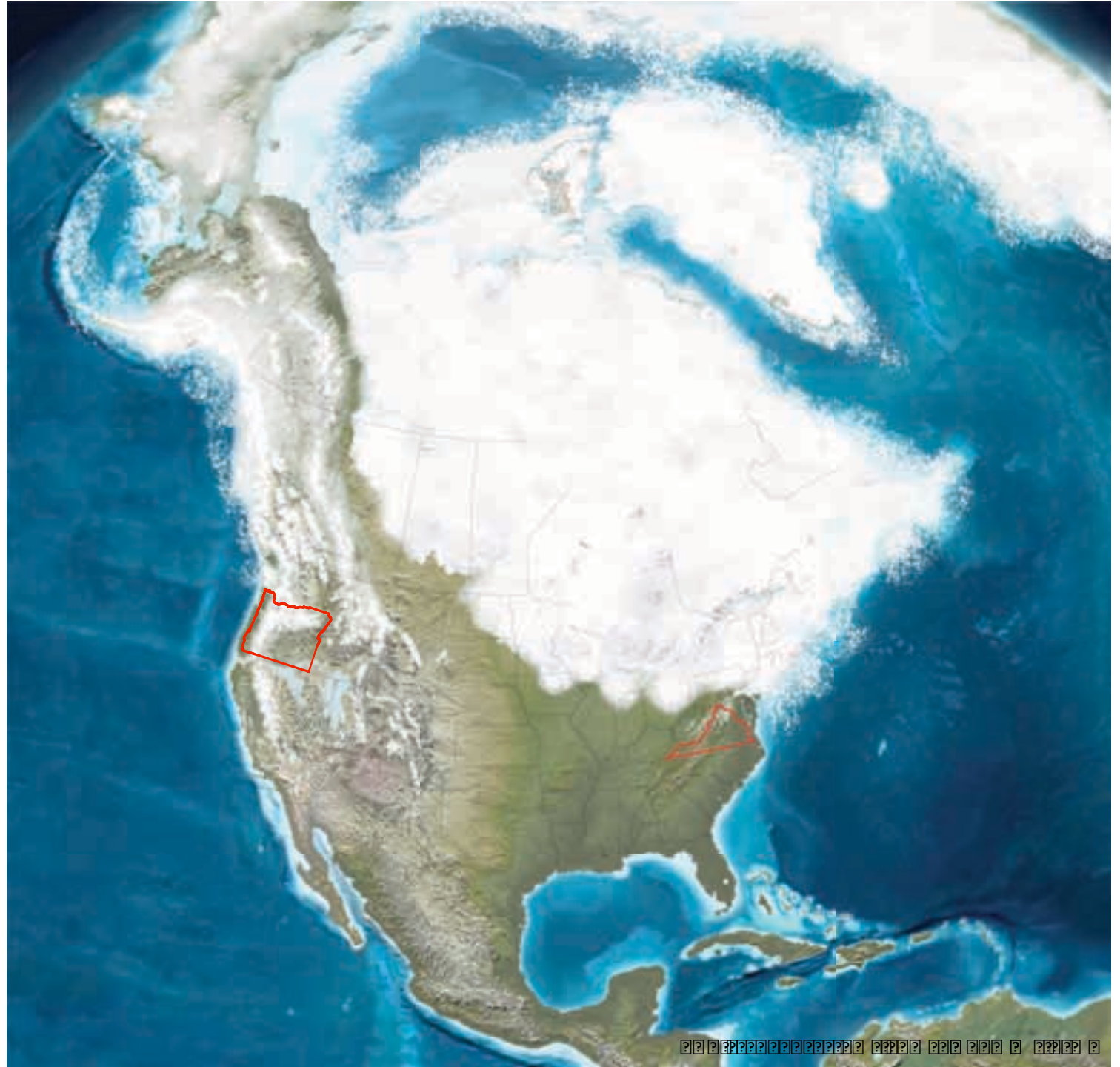
**Ron Blakey
Northern Arizona
University**



Holocene

**12,500
Years Ago**

**Ron Blakey
Northern Arizona
University**



Now

Present
Day

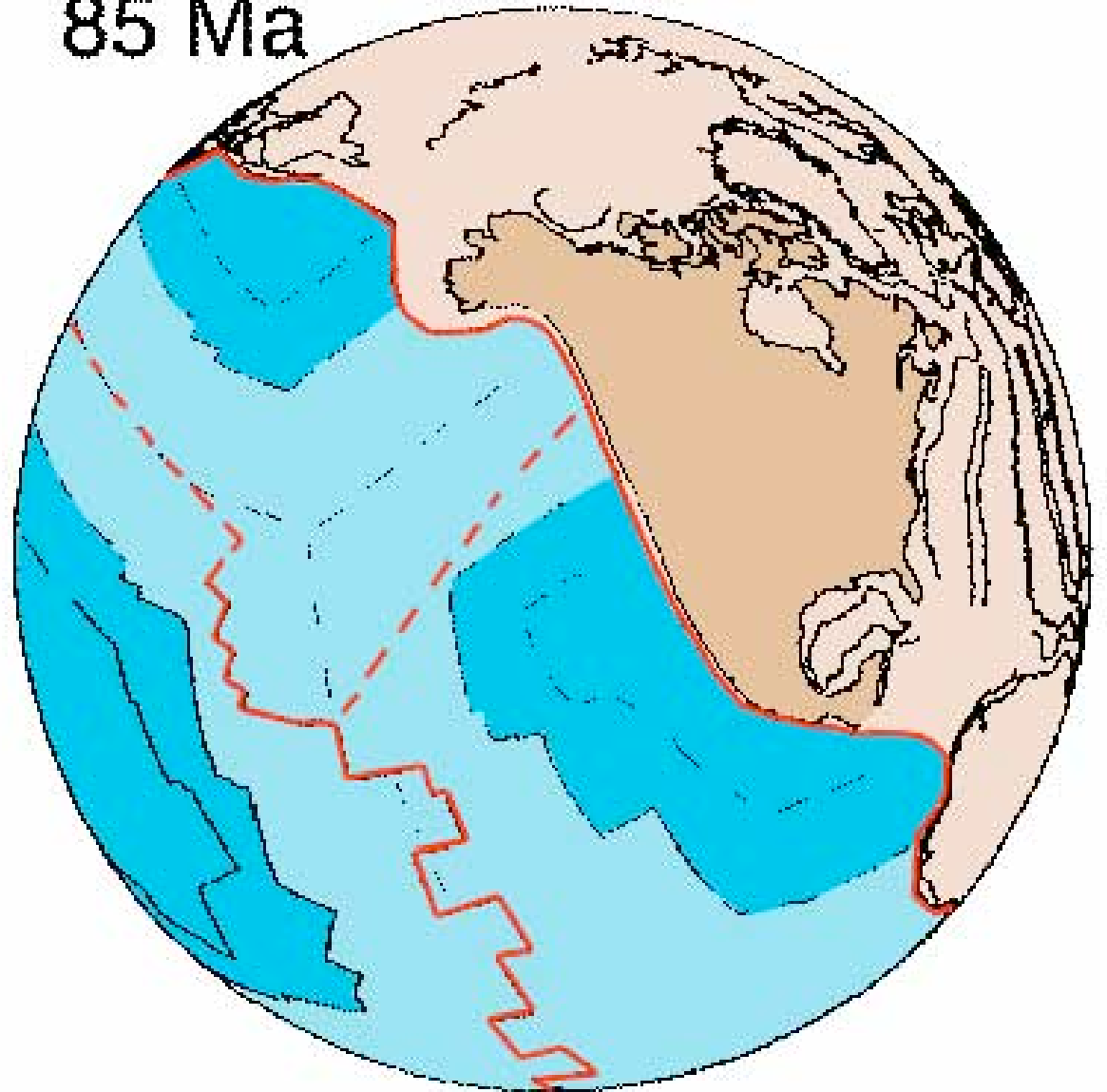
Ron Blakey
Northern Arizona
University



85 Ma

Tectonic Development of Western North America

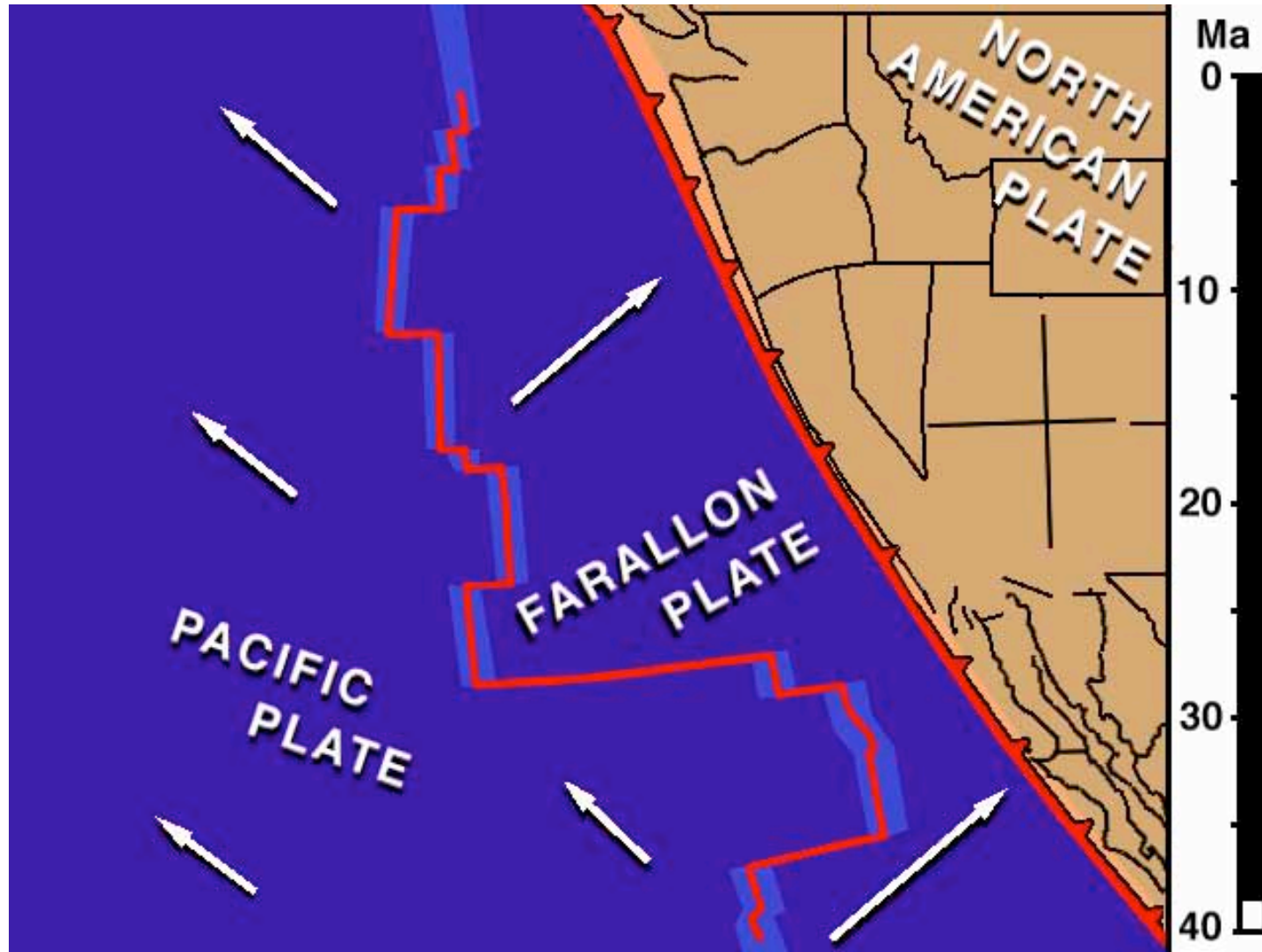
85 Million Years Ago to
the Present



From: Tanya Atwater
Educational Multimedia Visualization Center
Department of Earth Science
University of California at Santa Barbara

<http://emvc.geol.ucsb.edu>

Tectonic Development of the Pacific Northwest 40 Million Years Ago to the Present



Educational Multimedia Visualization Center

From: Tanya Atwater

Department of Earth Science

University of California at Santa Barbara

<http://emvc.geol.ucsb.edu>

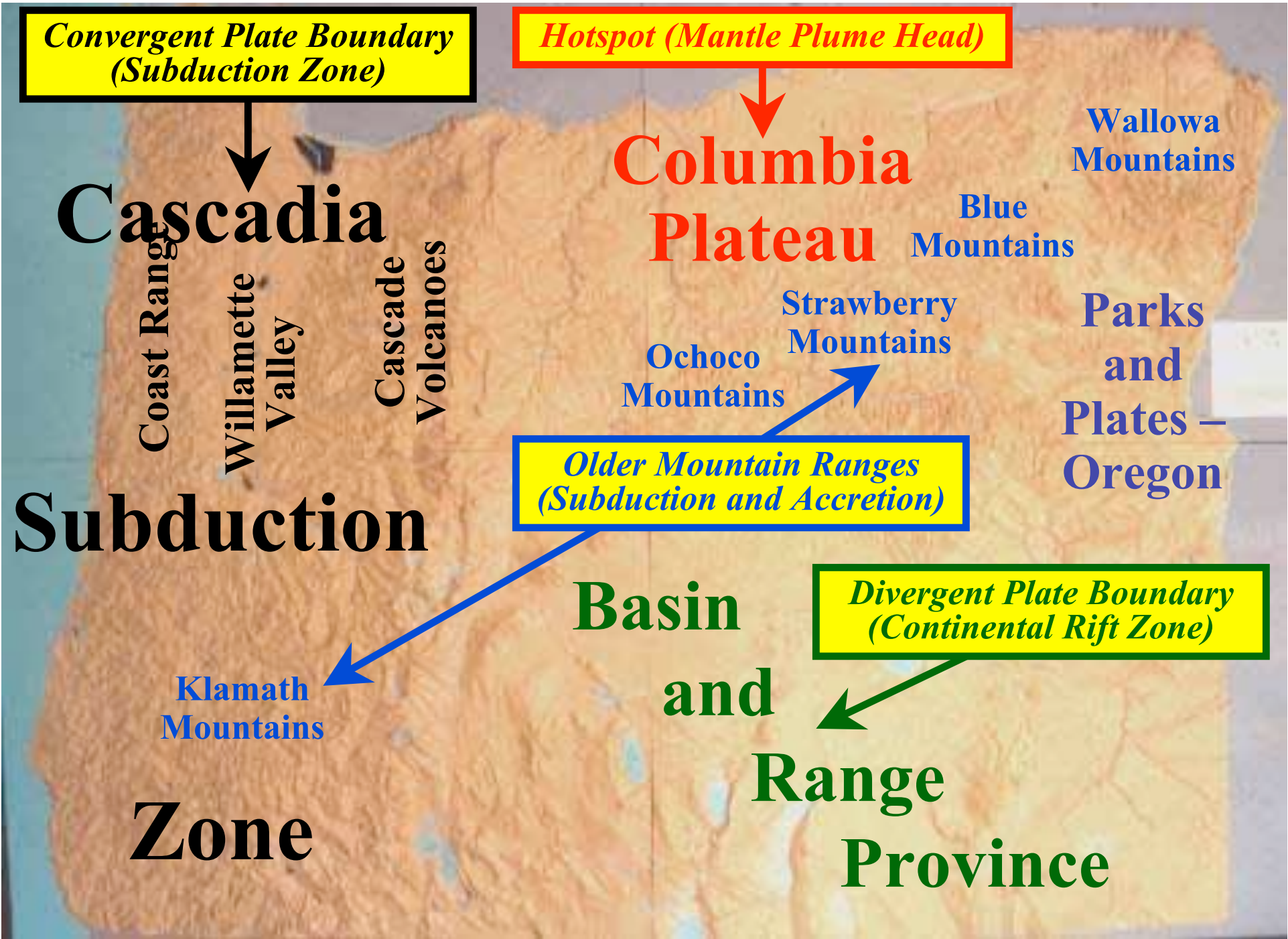


PLATE BOUNDARIES

- Divergent:

- Plates move away from one another.
- Volcanoes and Shallow Earthquakes



- Convergent:

- Plates move toward one another.
- Volcanoes and very large earthquakes



- Transform:

- Plates slide past one another.
- Earthquakes but no volcanoes



- (Hotspot):

- Plate rides over plume of hot mantle.
- Lots of volcanism.

