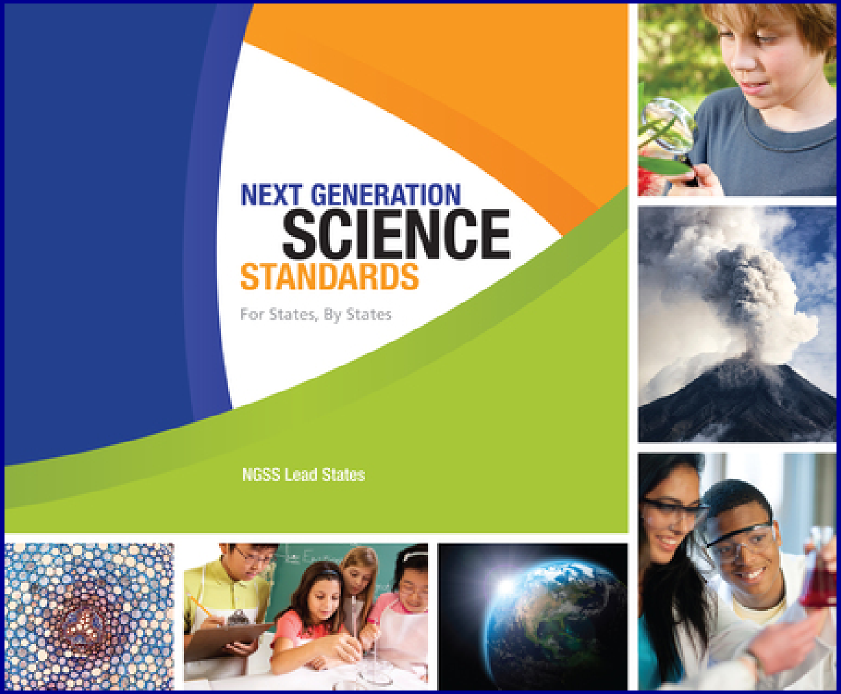
Geoheritage and the Future of K-12 Geoscience Education



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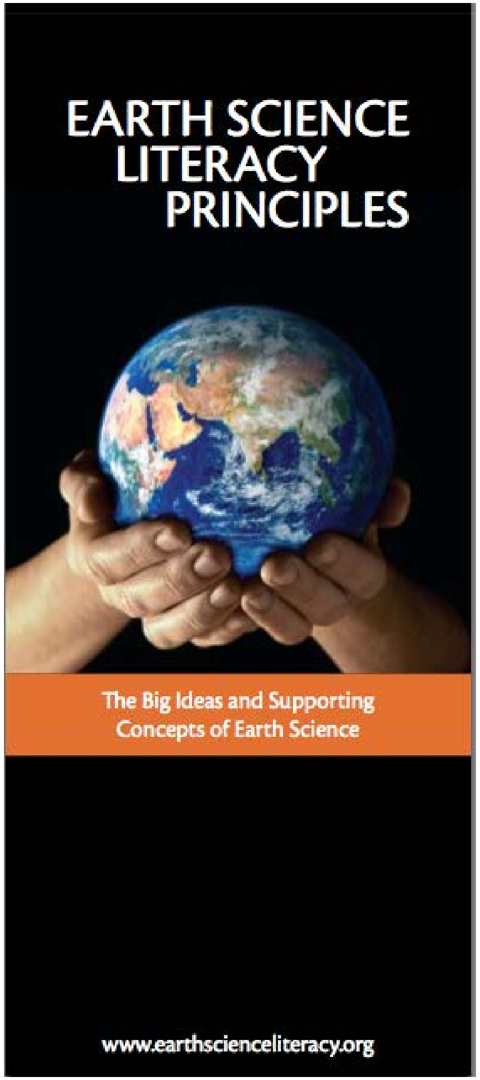


www.earthscienceliteracy.org

Free copies of the brochure available

BIG IDEA 2. Earth is 4.6 billion years old.

2.1 Earth's rocks and other materials provide a record of its history. Earth scientists use the structure, sequence, and properties of rocks, sediments, and fossils to reconstruct events in Earth's history. Decay rates of radioactive elements are the primary means of obtaining numerical ages of rocks and organic remains. Understanding geologic processes active in the modern world is crucial to interpreting Earth's past.

2.2 Our Solar System formed from a vast cloud of gas and dust 4.6 billion years ago. Some of this gas and dust was the remains of the supernova explosion of a previous star; our bodies are therefore made of "stardust." This age of 4.6 billion years is well established from the decay rates of radioactive elements found in meteorites and rocks from the Moon.

2.3 Earth formed from the accumulation of dust and gas, and multiple collisions of smaller planetary bodies. Driven by gravity, Earth's metallic core formed as iron sank to the center. Rock surrounding the core was mostly molten early in Earth's history, and slowly cooled to form Earth's mantle and crust. The atoms of different elements combined to make minerals, which combined to make rocks. Earth's ocean and atmosphere began to form more than 4 billion years ago from the rise of lighter materials out of the mantle.

2.4 Earth's crust has two distinct types: continental and oceanic. Continental crust persists at Earth's surface and can be billions of years old. Oceanic crust continuously forms and recycles back into the mantle; in the ocean, it is nowhere older than about 200 million years.

2.5 Studying other objects in the solar system helps us learn Earth's history. Active geologic processes such as plate tectonics and erosion have destroyed or altered most of Earth's early rock record. Many aspects of Earth's early history are revealed by objects in the solar system that have not changed as much as Earth has.

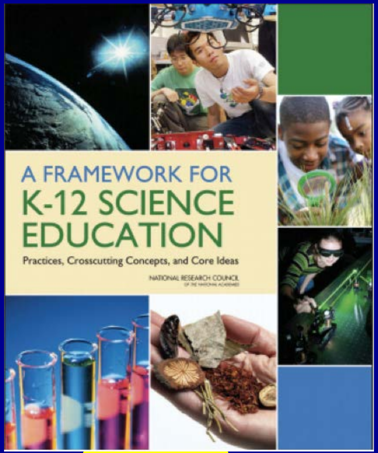
The Grand Canyon represents one of the most awe-inspiring landscapes in the United States. At the deepest parts of the canyon, nearly two-billion-year-old metamorphic rock is exposed. The Colorado River has cut through layers of colorful sedimentary rock as the Colorado Plateau has uplifted.

2.6 Life on Earth began more than 3.5 billion years ago. Fossils indicate that life began with single-celled organisms, which were the only life forms for billions of years. Humans (*Homo sapiens*) have existed for only a very small fraction (about 0.004%) of Earth's history.

2.7 Over Earth's vast history, both gradual and catastrophic processes have produced enormous changes. Supercontinents formed and broke apart, the compositions of the atmosphere and ocean changed, sea level rose and fell, living species evolved and went extinct, ice sheets advanced and melted away, meteorites slammed into Earth, and mountains formed and eroded away.

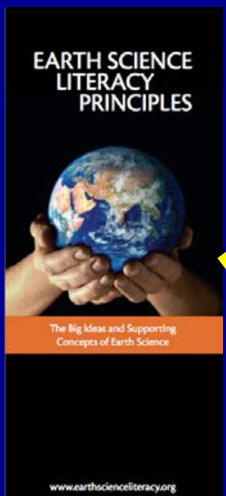
Timeline for the NGSS

2009

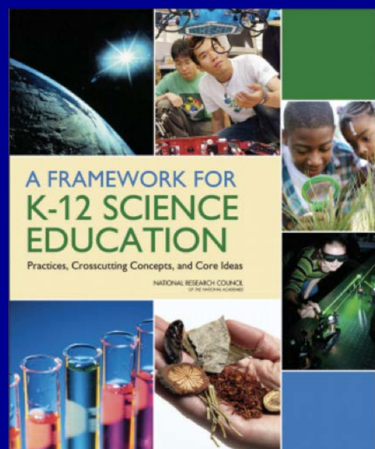


2011

Timeline for the NGSS



2009

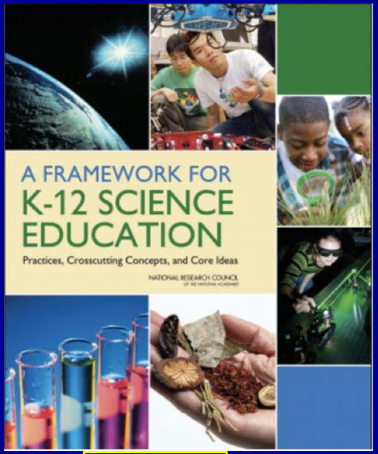


2011

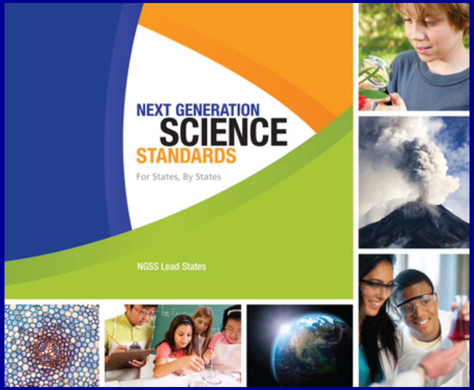
2013

Timeline for the NGSS

2009



2011



2013

Teacher Development

Curricula

Instructional Materials

Instruction

Assessment

2020

Coauthor of >35 K-12 Science Textbook Volumes

Next Generation Science: State-wise Adoption

Adopting States:

Arkansas
California
Connecticut
Delaware
Dist. of Col.
Hawaii
Illinois
Iowa
Kansas
Kentucky
Maine
Maryland
Michigan
Nevada
N. Hampshire
New Jersey
New Mexico
Oregon
Rhode Isl.
Vermont
Washington

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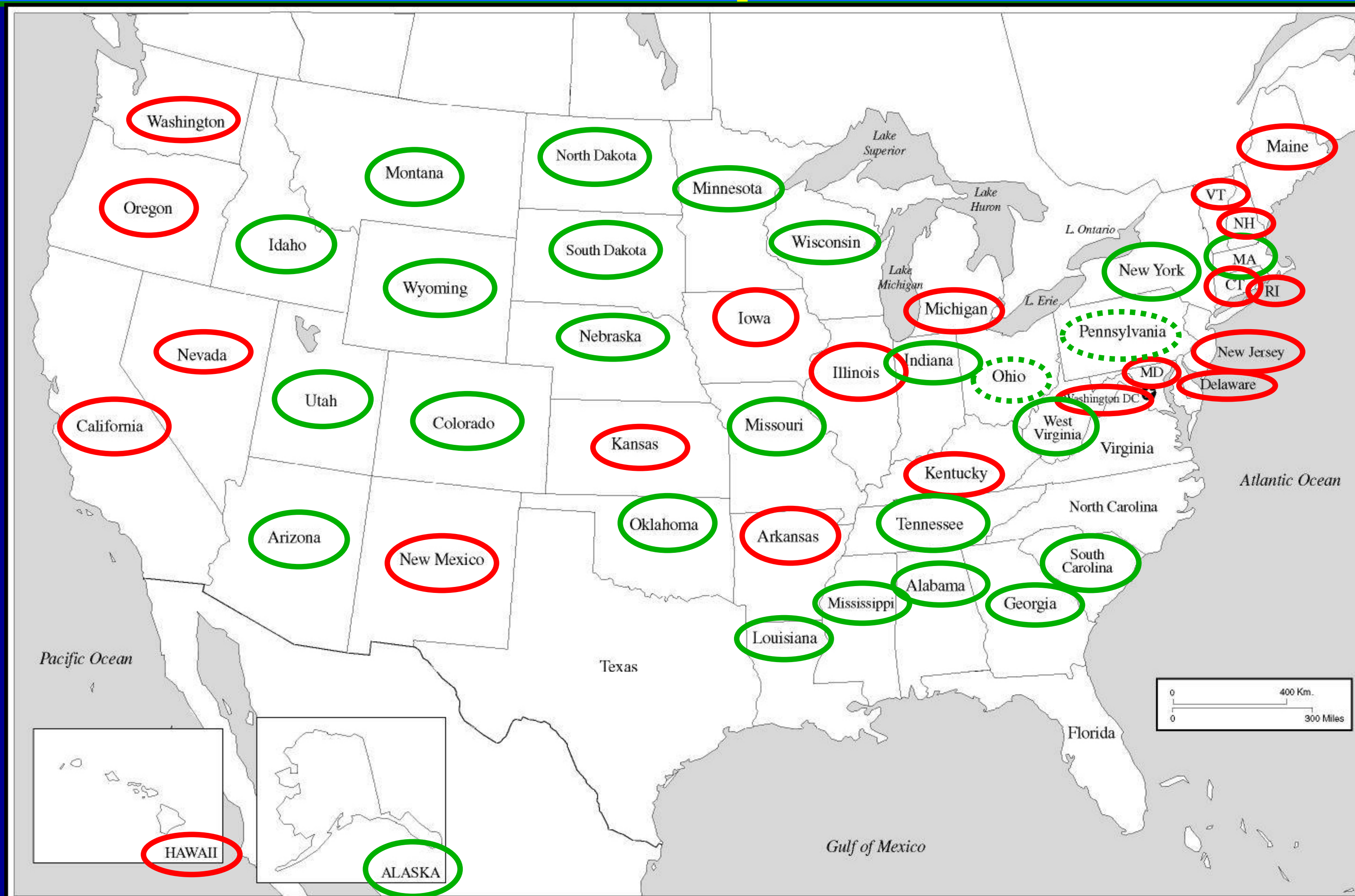

NGSS Adapting: Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, Wyoming

Next Generation Science: State-wise Adoption

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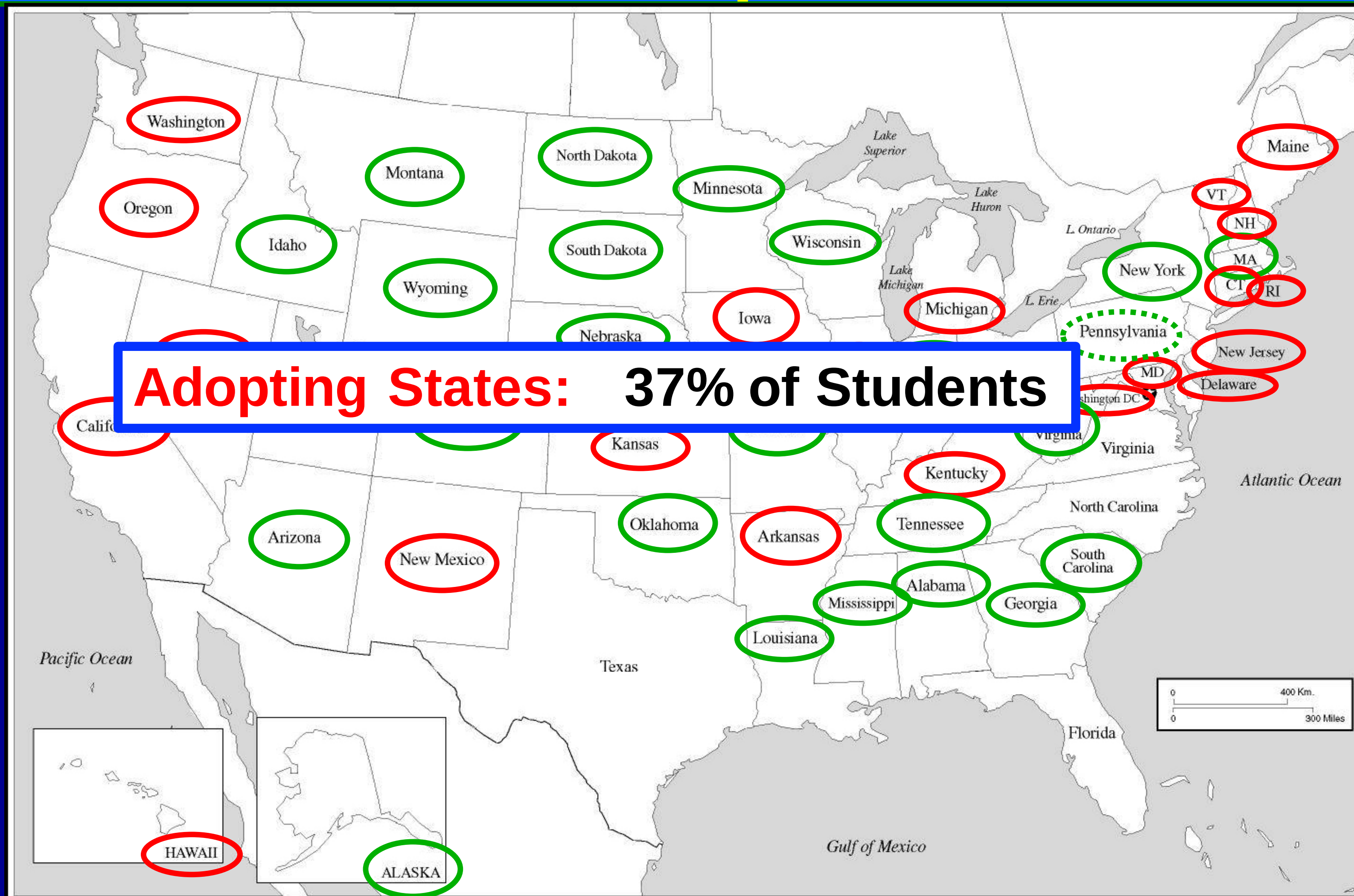

Adopting States: 37% of Students

NGSS Adapting: Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, Wyoming

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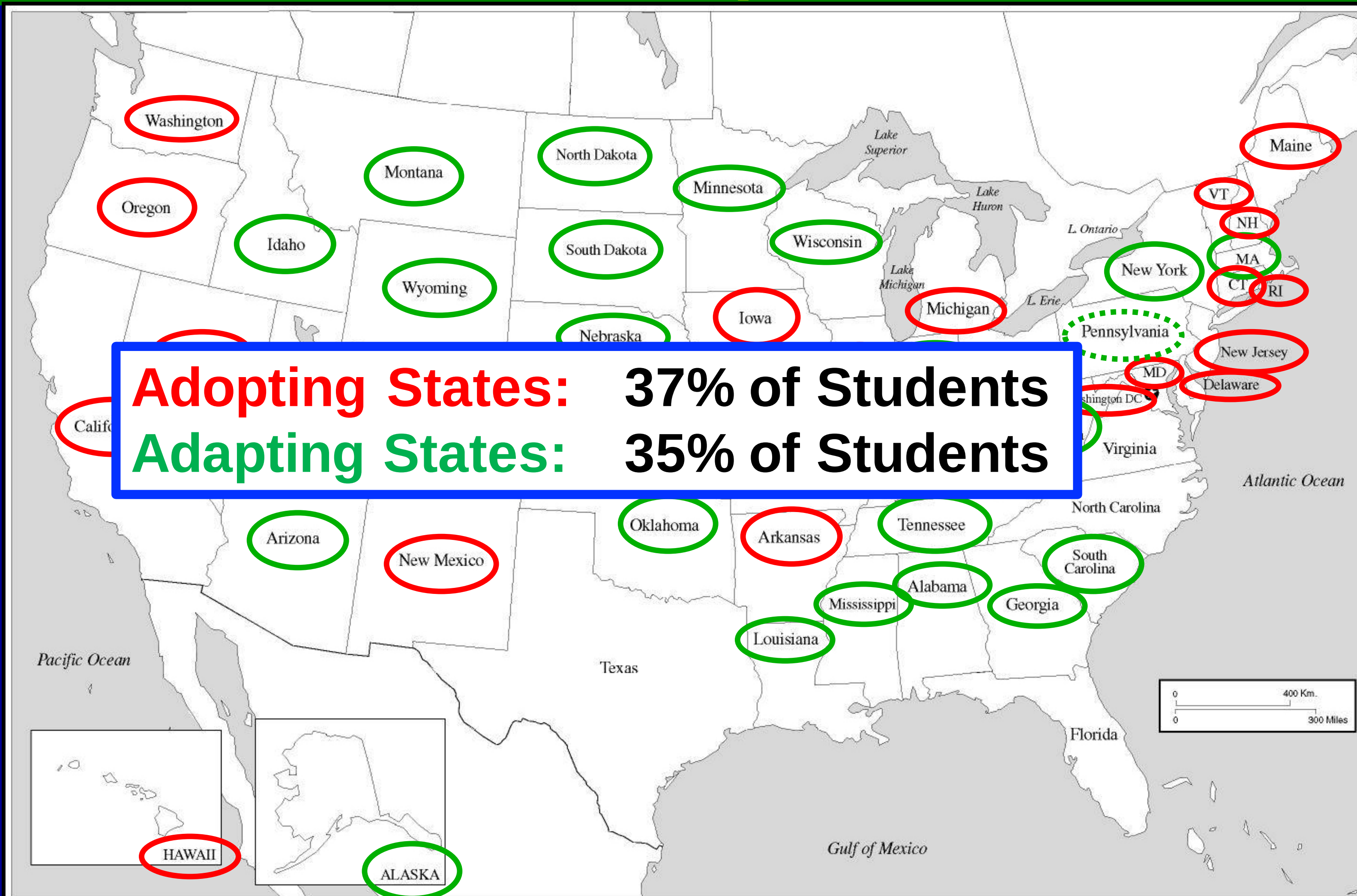

Adopting States: 37% of Students

Adapting States: 35% of Students

NGSS Adapting: Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, Wyoming

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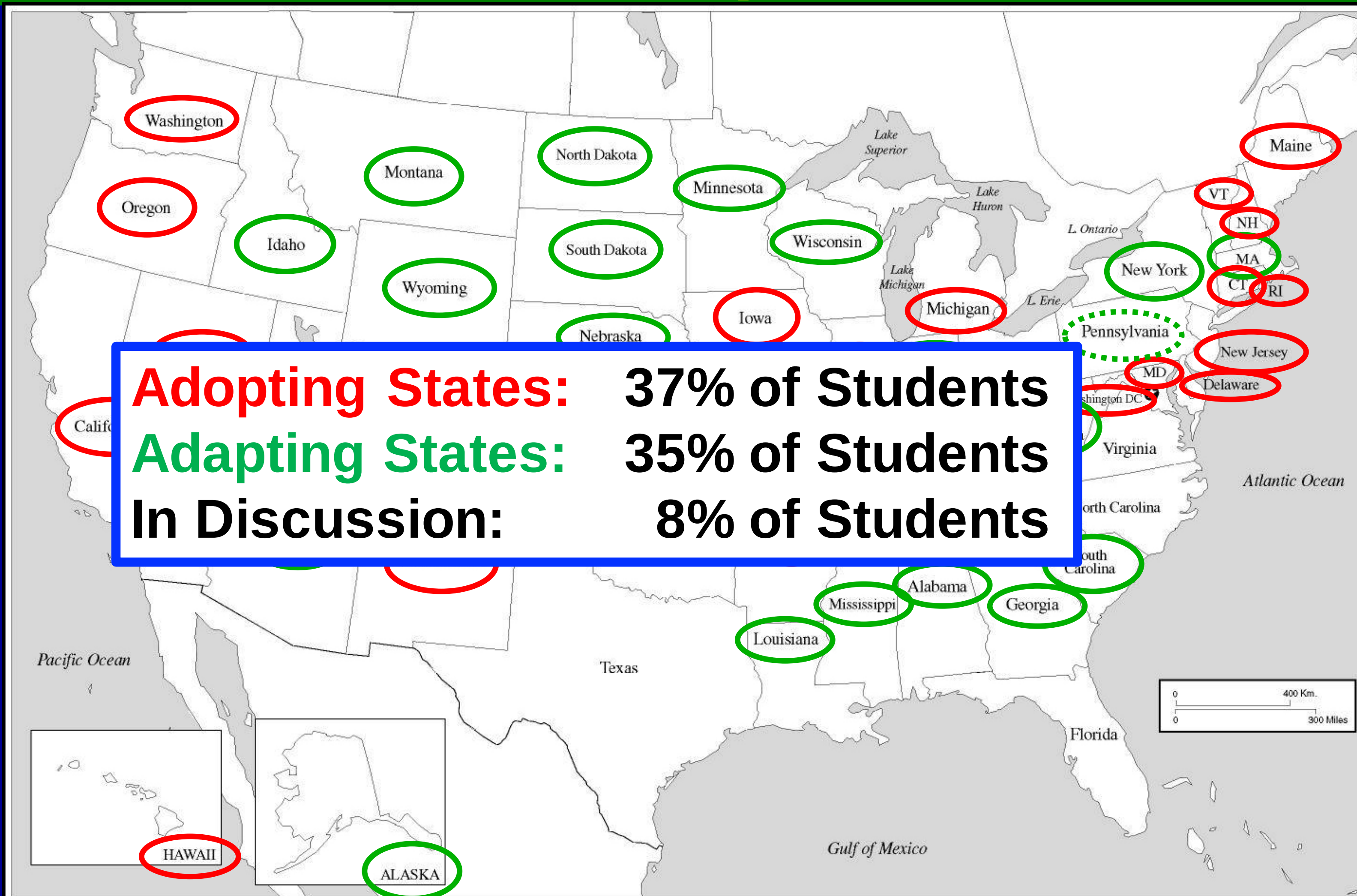

NGSS Adapting: Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, Wyoming

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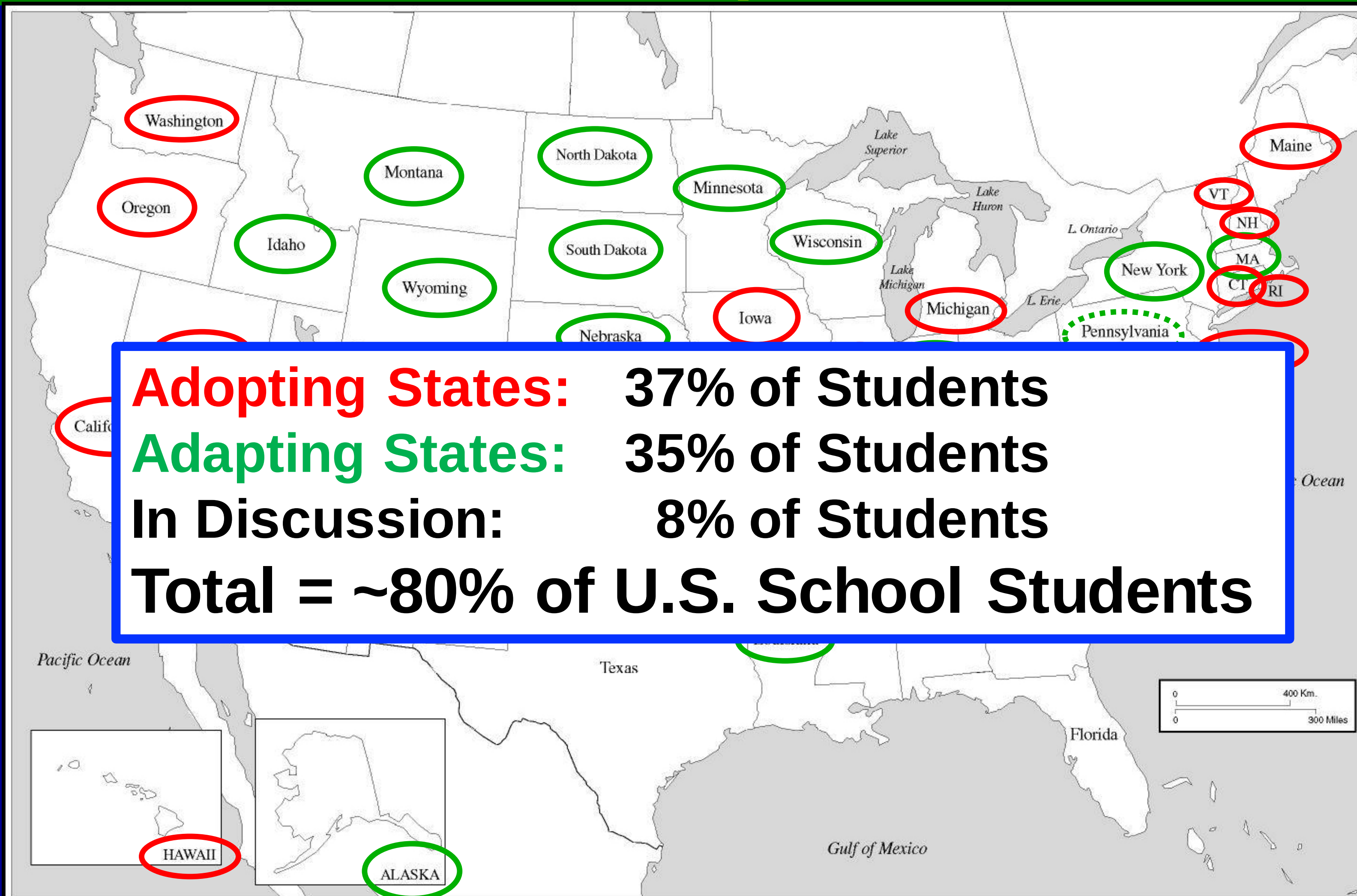
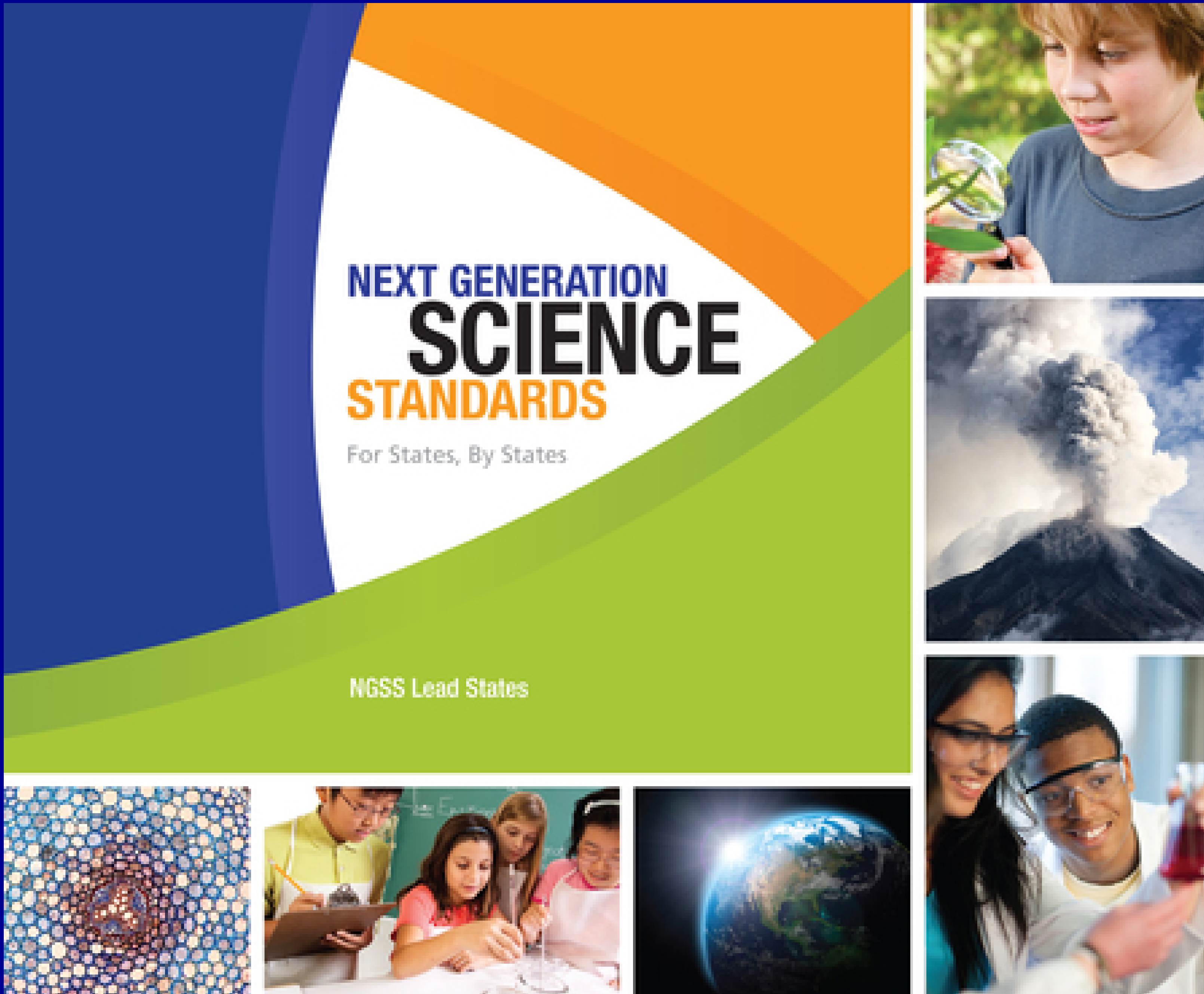


Adopting States: 37% of Students
Adapting States: 35% of Students
In Discussion: 8% of Students
Total = ~80% of U.S. School Students

NGSS Adapting: Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, Wyoming


NEXT GENERATION
SCIENCE
STANDARDS
For States, By States
NGSS Lead States

Next Generation Science Standards:

1) Central role of science and engineering ***practices***

Dimension #1: The Practices of ***Science*** and ***Engineering*** (SEPs)

1. Asking questions (*for science*) and defining problems (*for engineering*)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (*for science*) and designing solutions (*for engineering*)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Next Generation Science Standards:

1) Central role of science and engineering ***practices***

2) Organized around ***important*** and ***relevant*** scientific ***core ideas***

Dimension #2: The *Disciplinary Core Ideas*

Physical Science	Life Science	Earth and Space Science
PS1 Matter and Its Interactions **PS1A Structure and Properties of matter** **PS1B Chemical Reactions** **PS1C Nuclear Processes** PS2 Motion and Stability: Forces and Interactions **PS2A Forces and Motion** **PS2B Types of Interactions** **PS2C Stability and Instability in Physical Systems** PS3 Energy **PS3A Definitions of Energy** **PS3B Conservation of Energy and Energy Transfer** **PS3C Relationship Between Energy and Forces** **PS3D Energy and Chemical Processes in Everyday Life** PS4 Waves and Their Applications in Technologies for Information Transfer **PS4A Wave Properties** **PS4B Electromagnetic Radiation** **PS4C Information Technologies and Instrumentation**	LS1 From Molecules to Organisms: Structures and Processes **LS1A Structure and Function** **LS1B Growth and Development of Organisms** **LS1C Organization for Matter and Energy Flow in Organisms** **LS1D Information Processing** LS2 Ecosystems: Interactions, Energy, and Dynamics **LS2A Interdependent Relationships in Ecosystems** **LS2B Cycles of Matter and Energy Transfer in Ecosystems** **LS2C Ecosystem Dynamics, Functioning, and Resilience** **LS2D Social Interactions and Group Behavior** LS3 Heredity: Inheritance and Variation of Traits **LS3A Inheritance of Traits** **LS3B Variation of Traits** LS4 Biological Evolution: Unity and Diversity **LS4A Evidence of Common Ancestry** **LS4B Natural Selection** **LS4C Adaptation** **LS4D Biodiversity and Humans**	ESS1 Earth's Place in the Universe **ESS1A The Universe and Its Stars** **ESS1B Earth and the Solar System** **ESS1C The History of Planet Earth** ESS2 Earth's Systems **ESS2A Earth Materials and Systems** **ESS2B Plate Tectonics and Large-Scale System Interactions** **ESS2C The Roles of Water in Earth's Surface Processes** **ESS2D Weather and Climate** **ESS2E Biogeology** ESS3 Earth and Human Activity **ESS3A Natural Resources** **ESS3B Natural Hazards** **ESS3C Human Impacts on Earth Systems** **ESS3D Global Climate Change**

NGSS: Required Science

Elementary School: Life/Earth/Physical Integrated

Middle School: Grades 6-8

- 1 year of Life Science
- 1 year of Physical Science (Chemistry & Physics)
- 1 year of Earth and Space Science

High School: Grades 9-12

- 1 year of Life Science
- 1 year of Physical Science (Chemistry & Physics)
- 1 year of Earth and Space Science

Next Generation Science Standards:

1) Central role of science and engineering ***practices***

2) Organized around ***important*** and ***relevant*** scientific ***core ideas*** as well as the themes of ***crosscutting concepts***

Dimension #3: The Crosscutting Concepts

1. Patterns
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter
6. Structure and function
7. Stability and change

Next Generation Science Standards:

1) Central role of science and engineering ***practices***

2) Organized around ***important*** and ***relevant*** scientific ***core ideas*** as well as the themes of ***crosscutting concepts***

3) Learned through ***storylines of engaging phenomena***

NGSS: → Phenomenon-Based Learning

- Phenomena are defined through broad big-picture questions, usually of human relevance
- Challenges are approached holistically, viewed from a variety of perspectives

NGSS: → Phenomenon-Based Learning

- **PEEC: "***Student sense-making and solution-designing should be the context for student learning and a window into student understanding of all three dimensions of the standards"*

NGSS: → Phenomenon-Based Learning

- Essential Questions about Phenomena are explored through

STORYLINES

HS-ESS3-1 Earth and Human Activity

Performance Expectation

Students who demonstrate understanding can:

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

PRACTICES	*BIG IDEAS*	*X-CUTTING CONCEPTS*
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories. • Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**ESS3.A: Natural Resources** • Resource availability has guided the development of human society. **ESS3.B: Natural Hazards** • Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. - - - - - - - - - - - - - - - - ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** • Modern civilization depends on major technological systems.

Connections to other DCIs in this grade-band: N/A

Articulation of DCIs across grade-bands:
MS.LS2.A ; MS.LS4.D ; MS.ESS2.A ; MS.ESS3.A ; MS.ESS3.B

Common Core State Standards Connections:

ELA/Literacy -

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-ESS3-1)*

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS3-1)

Mathematics -

MP.2 Reason abstractly and quantitatively. *(HS-ESS3-1)*

HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-ESS3-1)*

HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-ESS3-1)*

HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-ESS3-1)*

HS-ESS3-1 Earth and Human Activity

Clarification Statement

Students who demonstrate understanding can:

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The Three-Dimensional Foundation Boxes

Connections to other DCIs in this grade-band: N/A

Articulation of DCIs across grade-bands:
MS.LS2.A ; **MS.LS4.D** ; **MS.ESS2.A** ; **MS.ESS3.A** ; **MS.ESS3.B**

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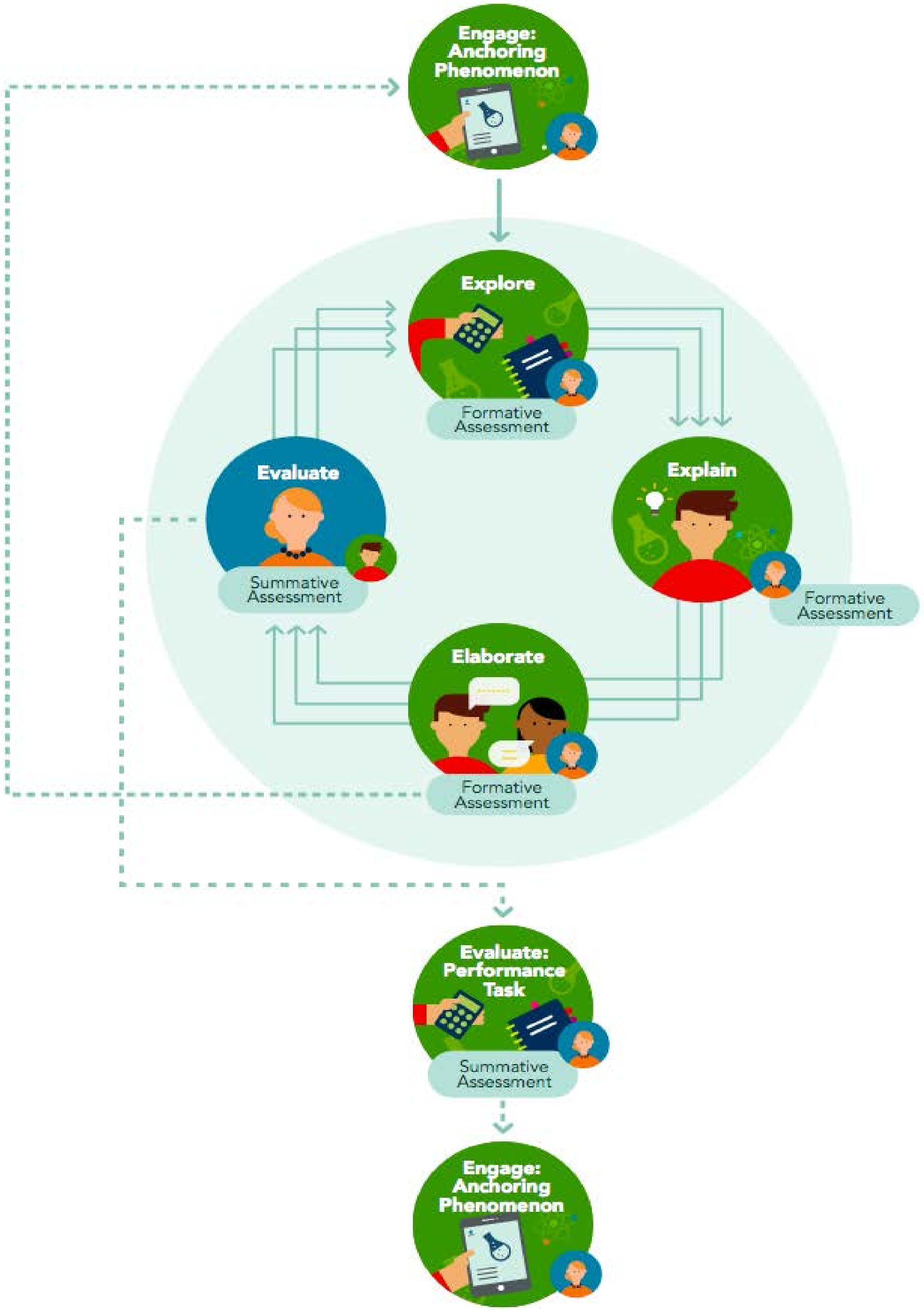
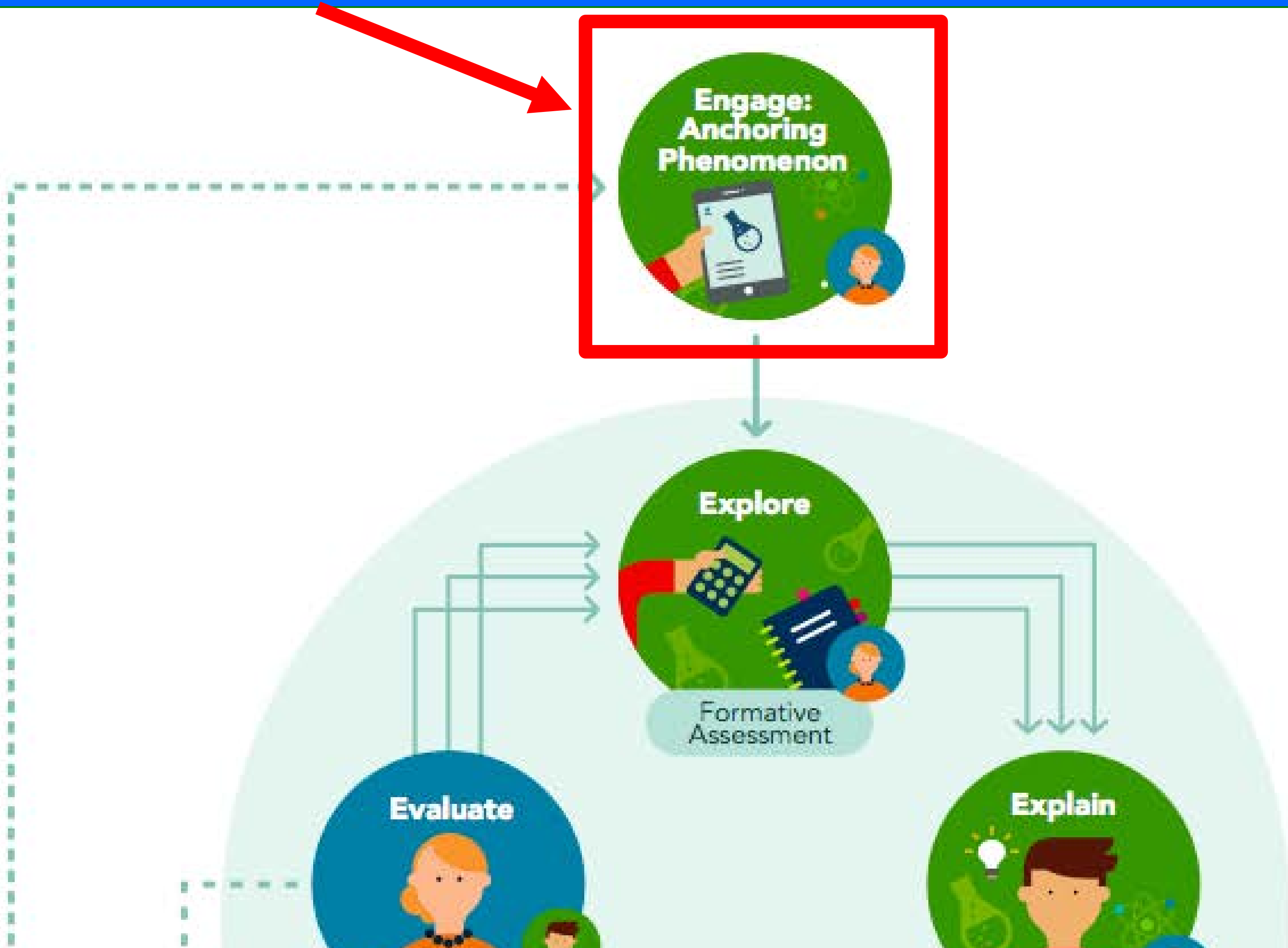
NGSS: → Phenomenon-Based Learning

Explored with the 5 E's



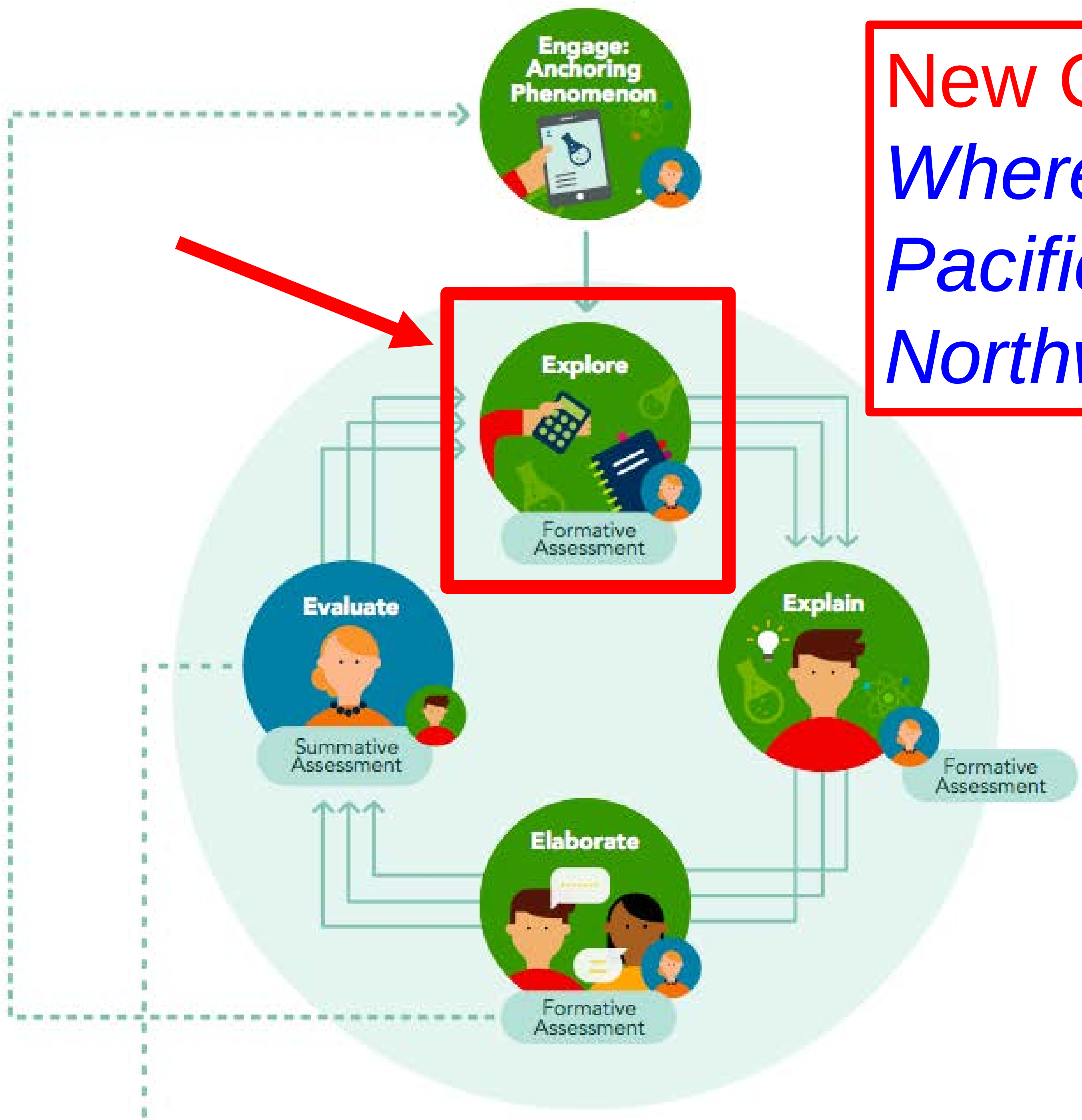
Choose an *Anchoring Phenomenon*



Choose an *Anchoring Phenomenon*

Choose an *Essential Question*

Why are there volcanoes in the Pacific Northwest?

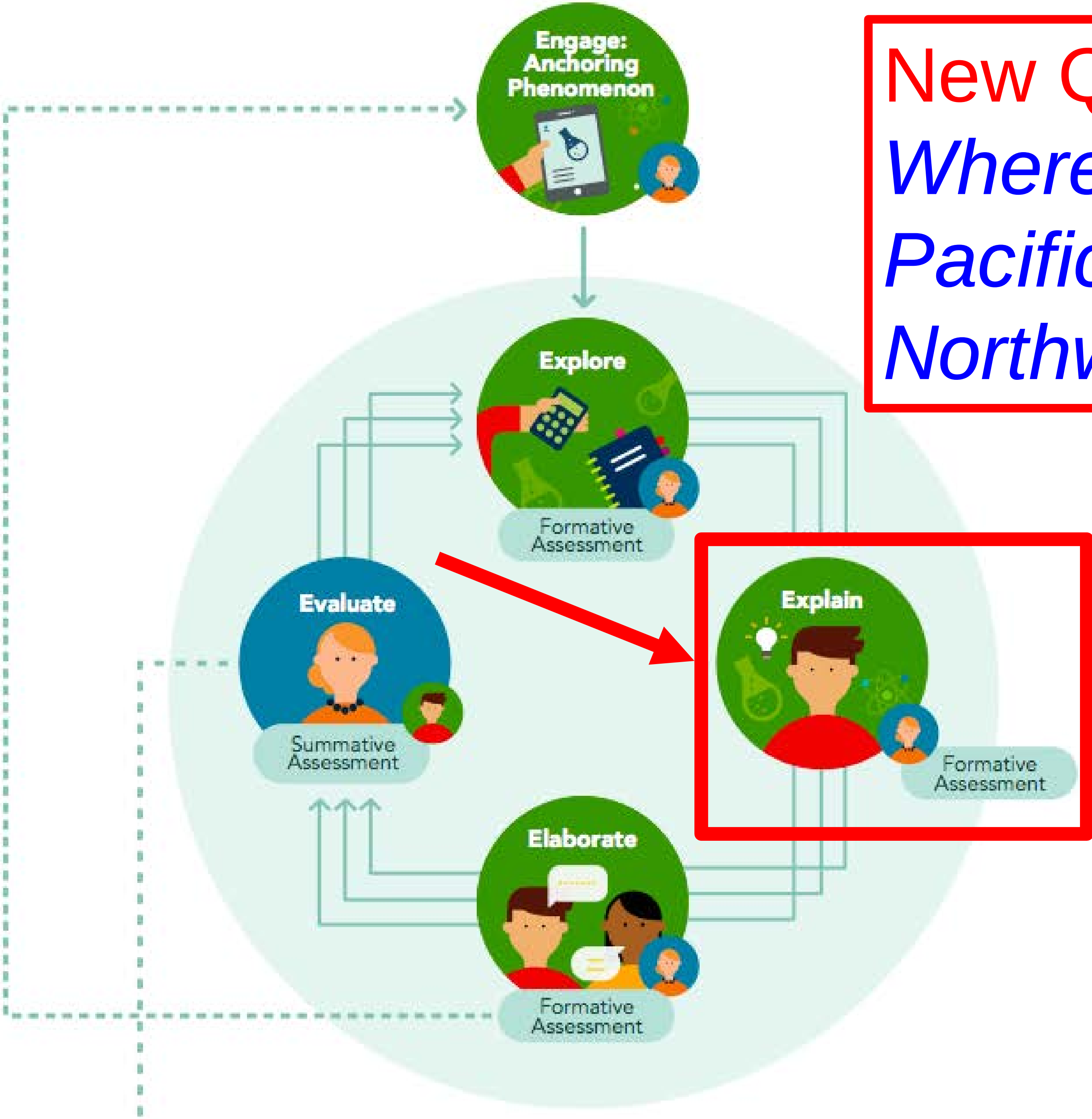


New Question:
Where is the Pacific Northwest?

New Question: *Where is the Pacific Northwest?*

New Question:

Where is the Pacific Northwest?



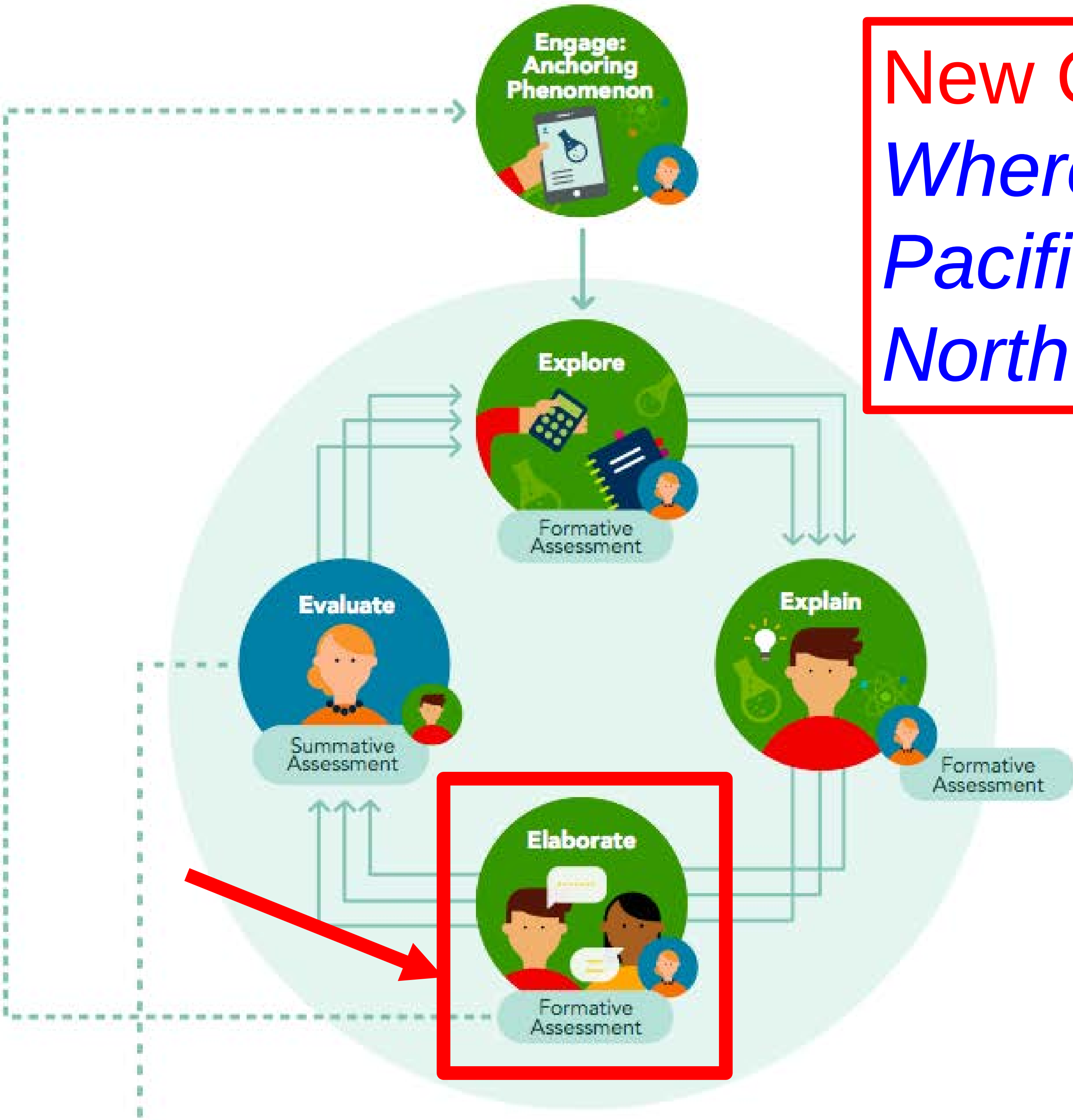
New Question: *Where is the Pacific Northwest?*

New Questions:

What is a map?

How do you use a map?

What are latitude and longitude?

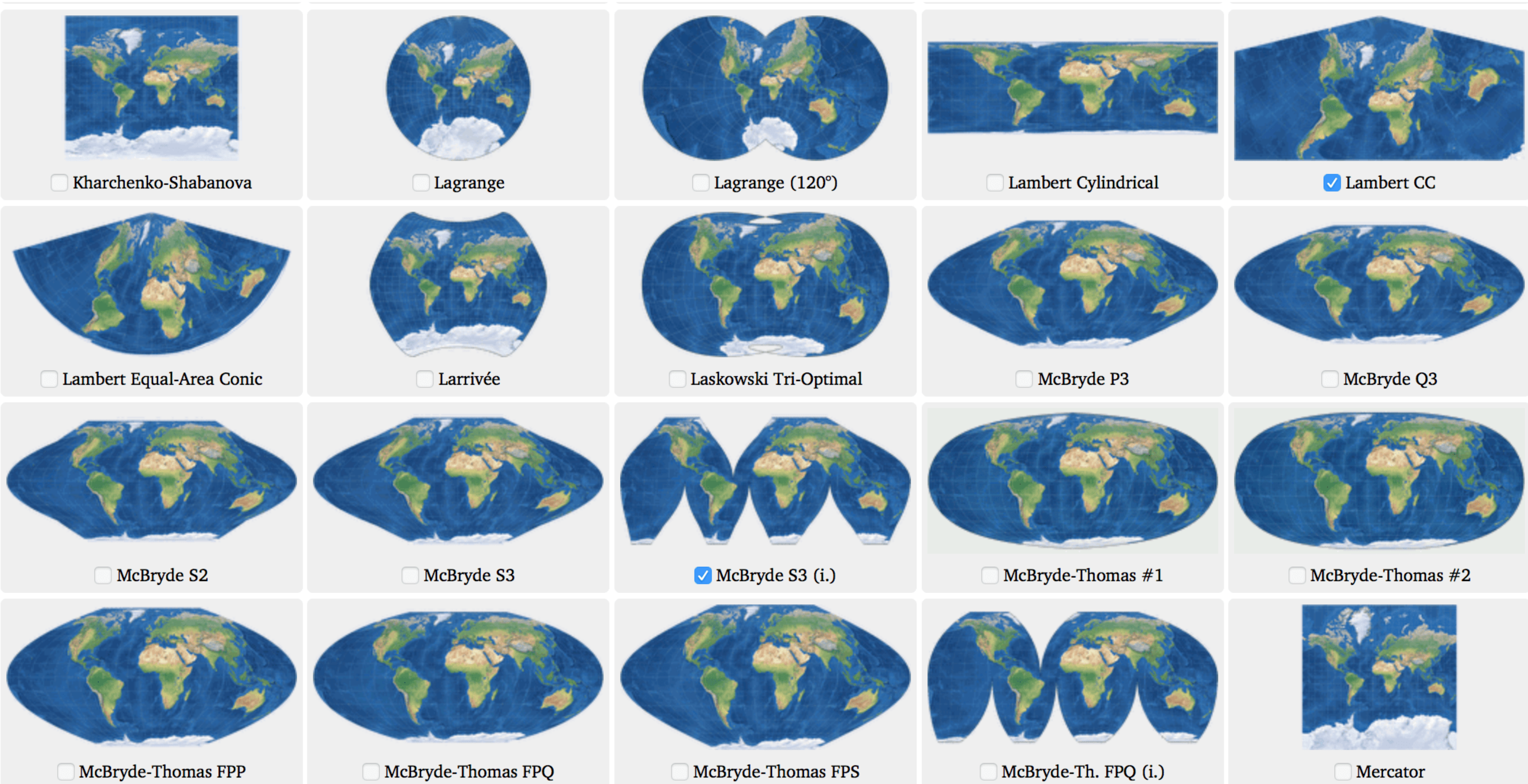


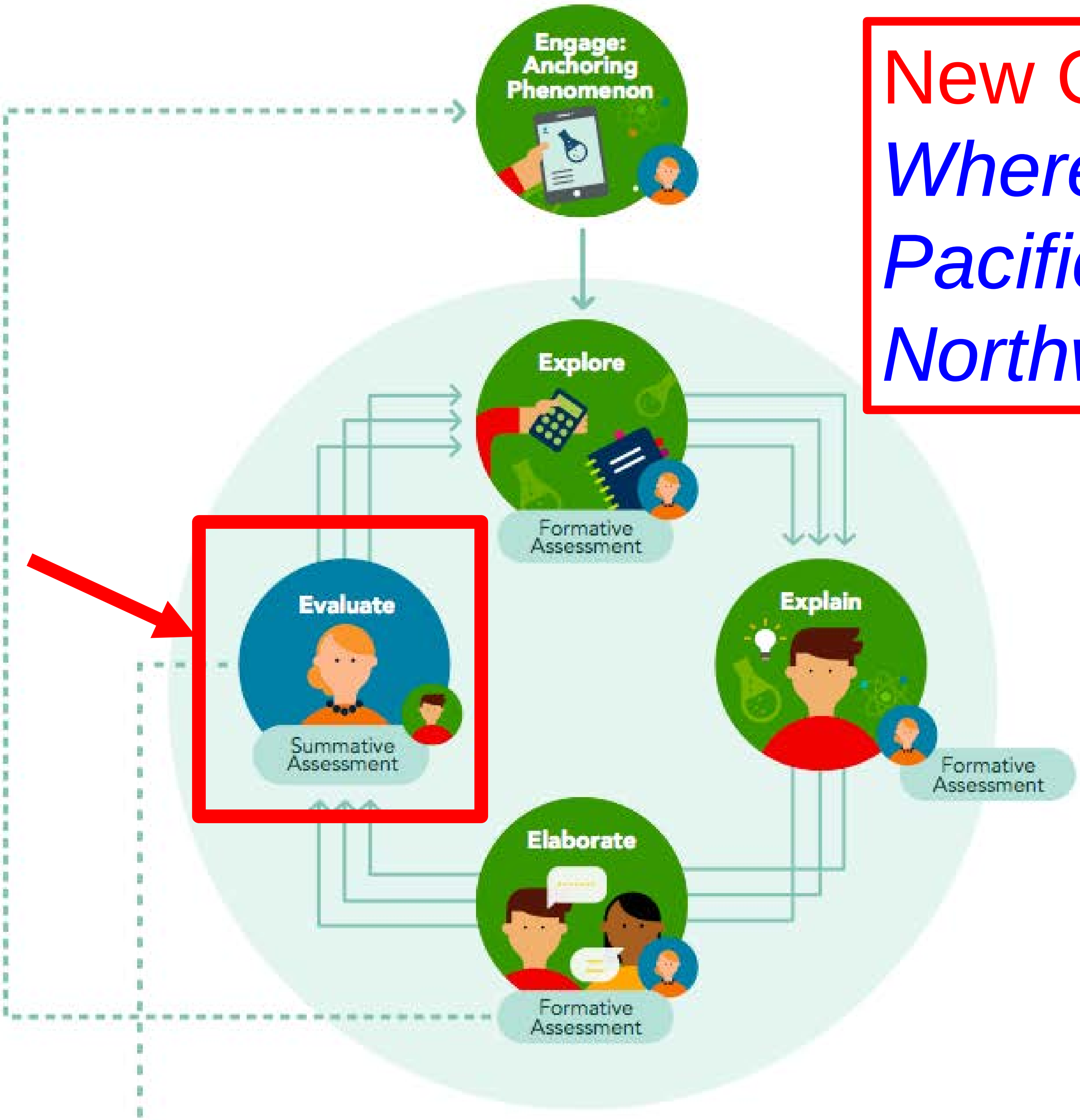
New Question:
Where is the Pacific Northwest?

New Question: *Why are there so many different types of maps?*

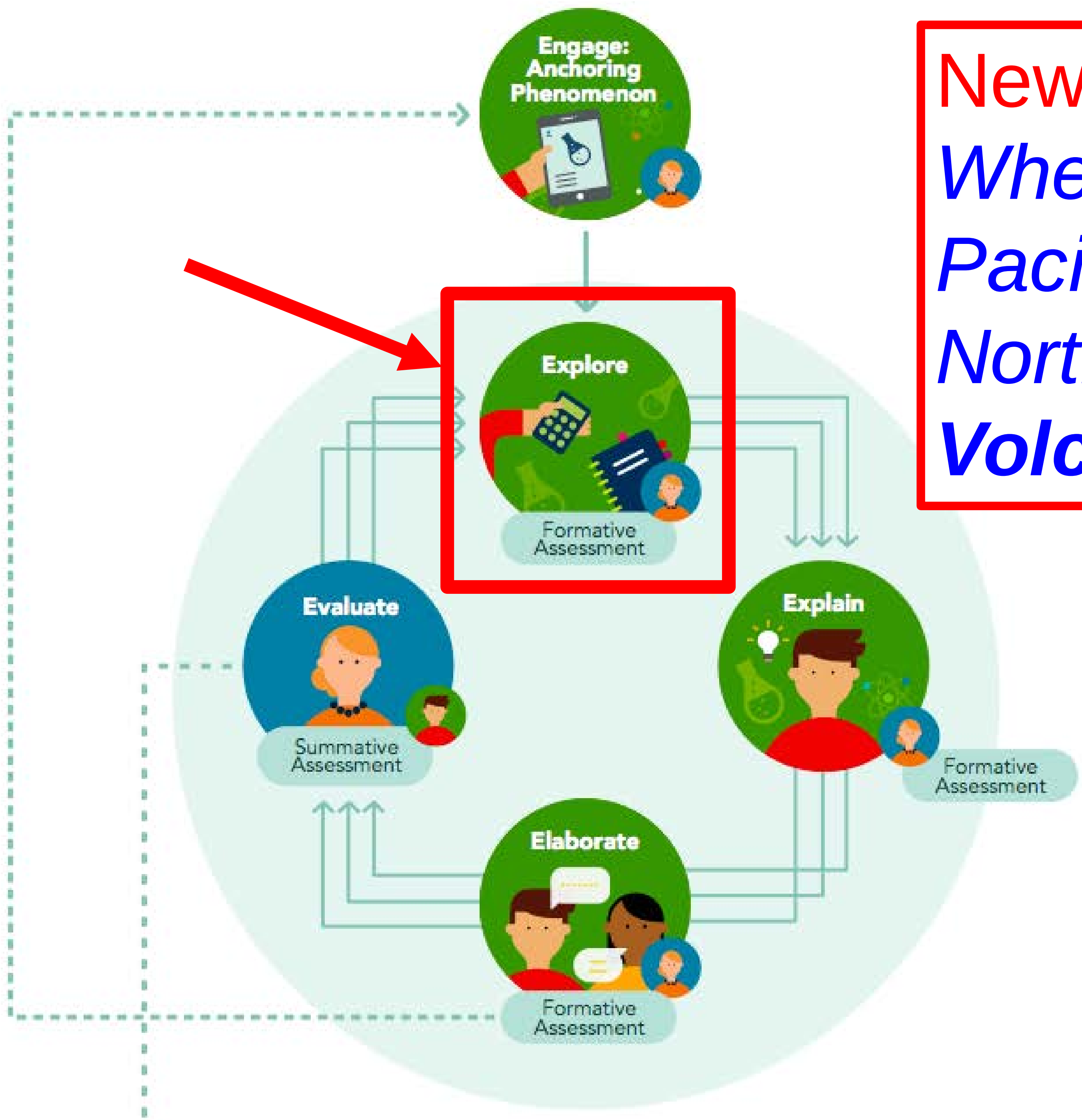
New Question: *Why are there so many different types of maps?*

New Question: *Why are there so many different kinds of map projections?*





New Question:
Where is the Pacific Northwest?

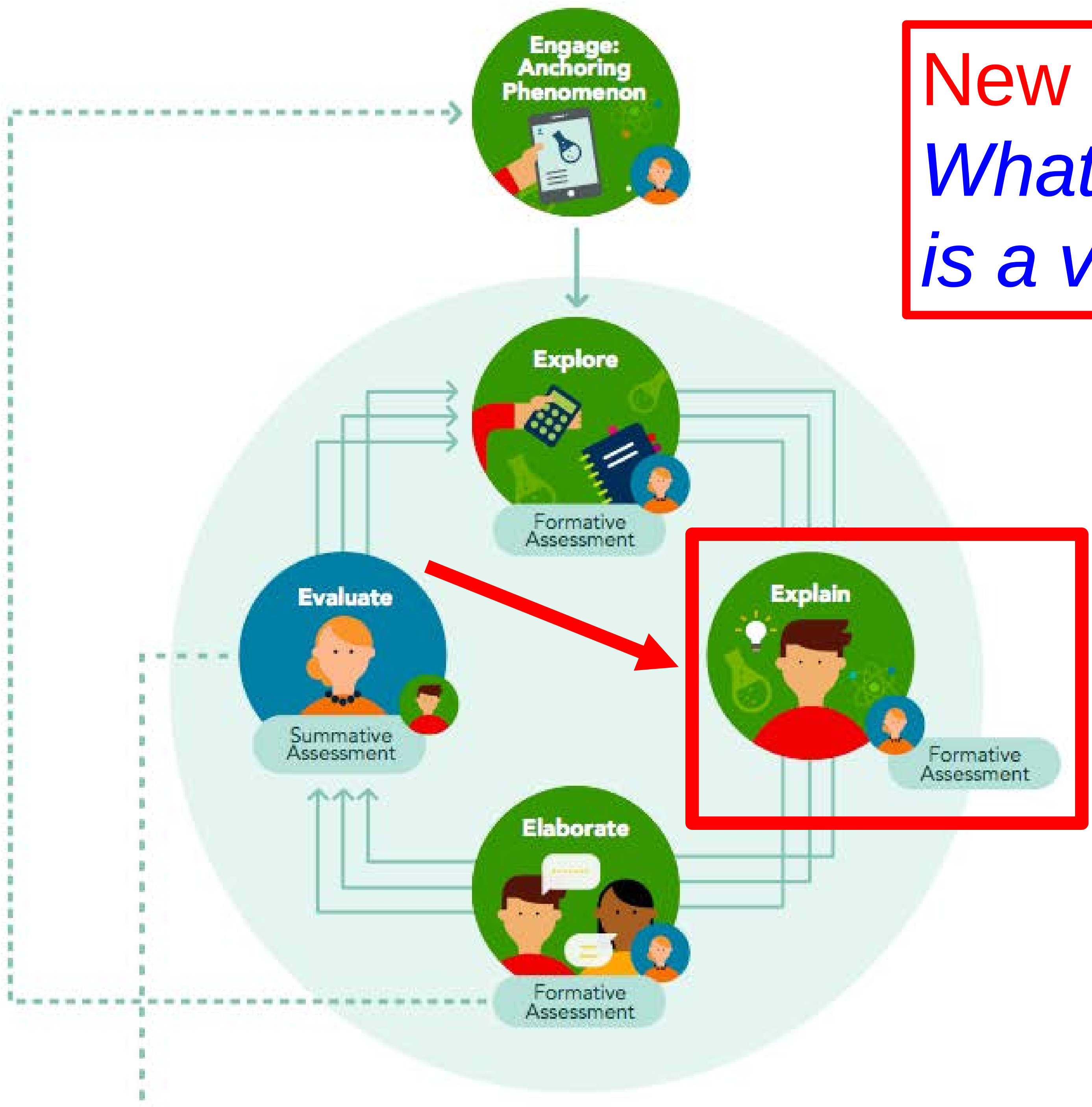


New Question:
Where are the Pacific Northwest ***Volcanoes****?*


Mount Baker
Glacier Peak
WASHINGTON
Mount Rainier
Mount Adams
Mount St.Helens
Mount Hood
Mount Jefferson
Three Sisters
Newberry
OREGON
Crater Lake
Medicine Lake
Mount Shasta
Lassen Peak
CALIFORNIA
100 km

New Question:

What, actually, is a volcano?

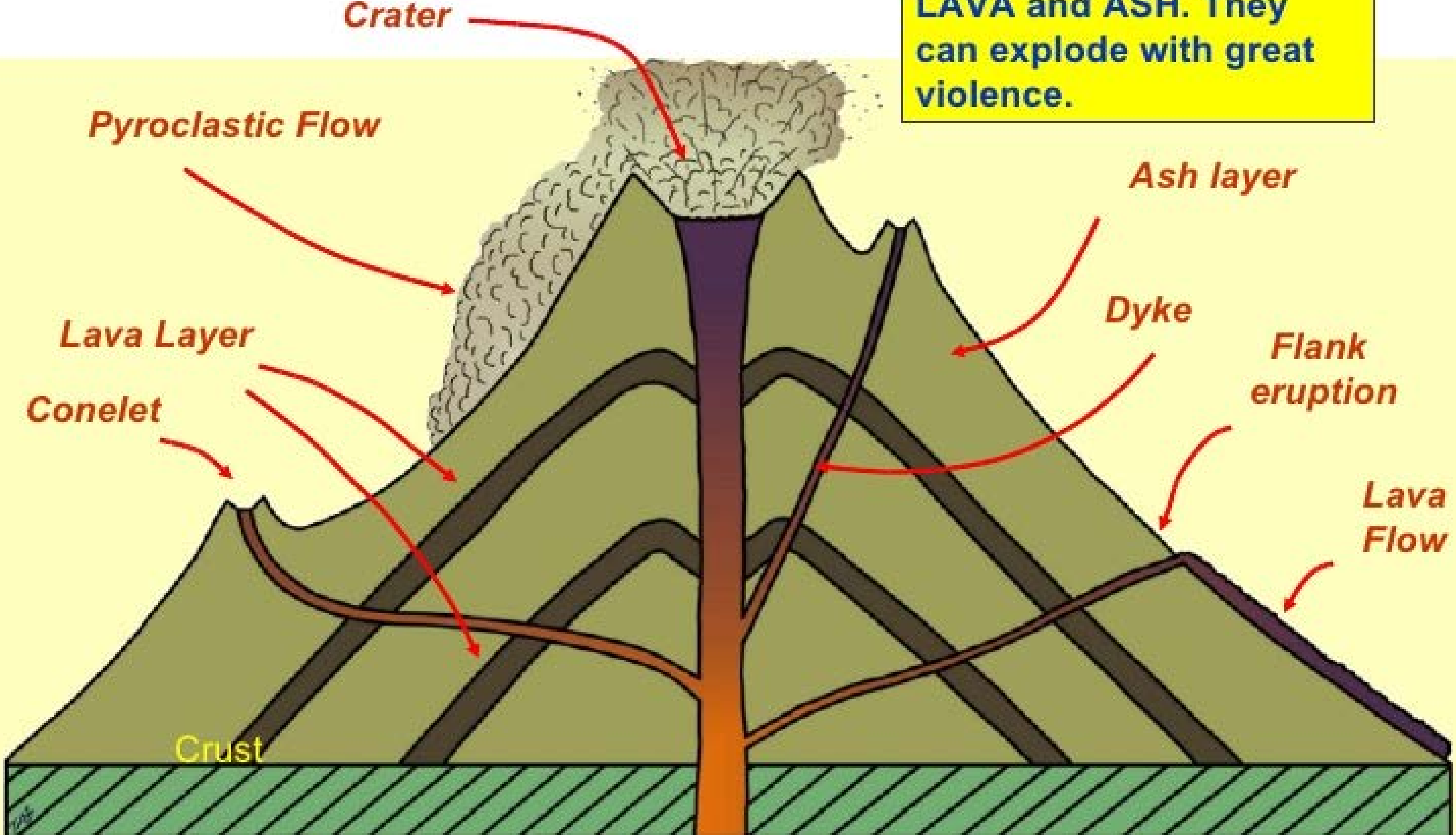


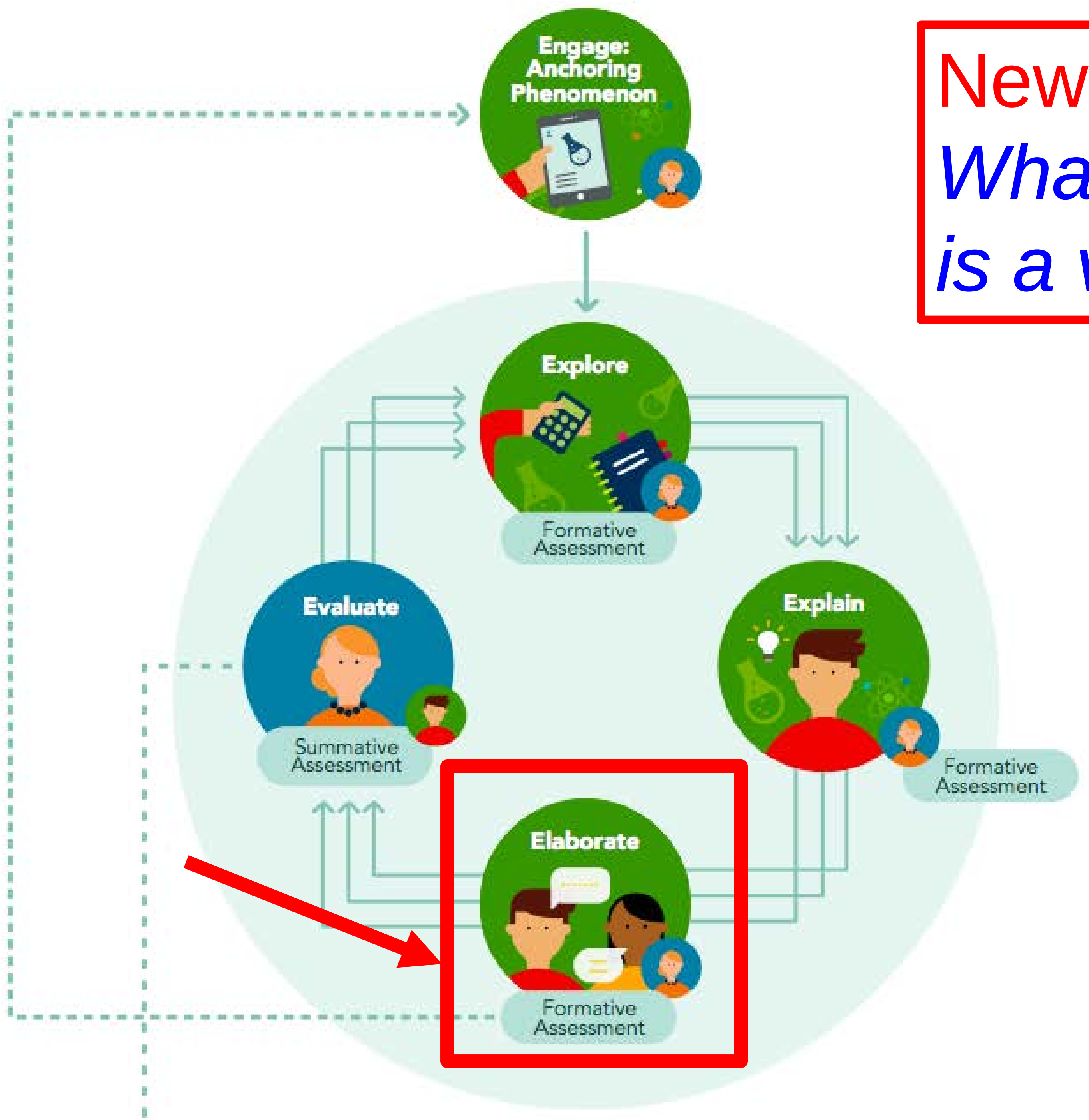
New Question:
What, actually, is a volcano?

Composite Cone

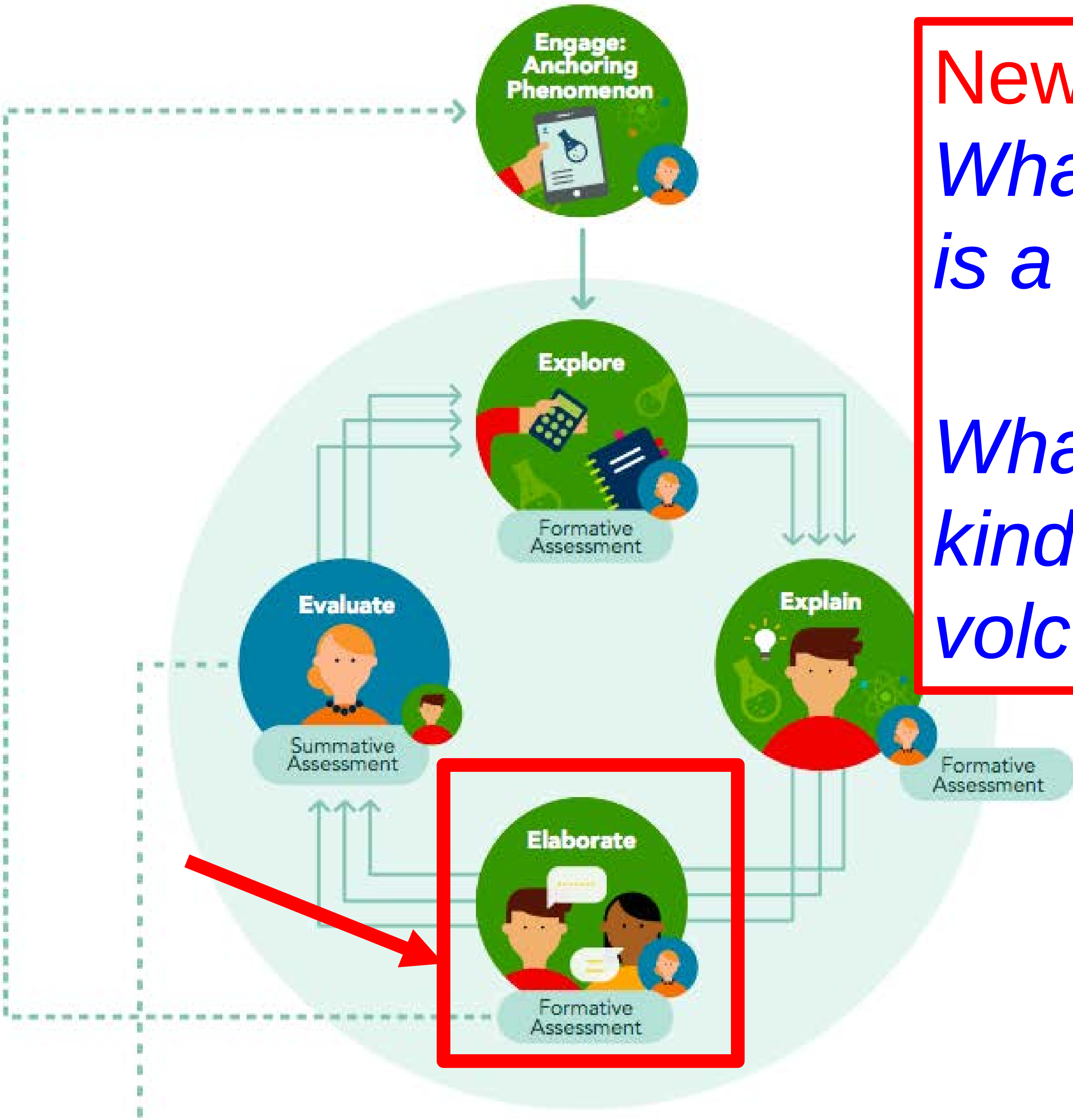
Mt St Helens - USA

The volcano is built up of alternate layers of LAVA and ASH. They can explode with great violence.





New Question:
What, actually, is a volcano?

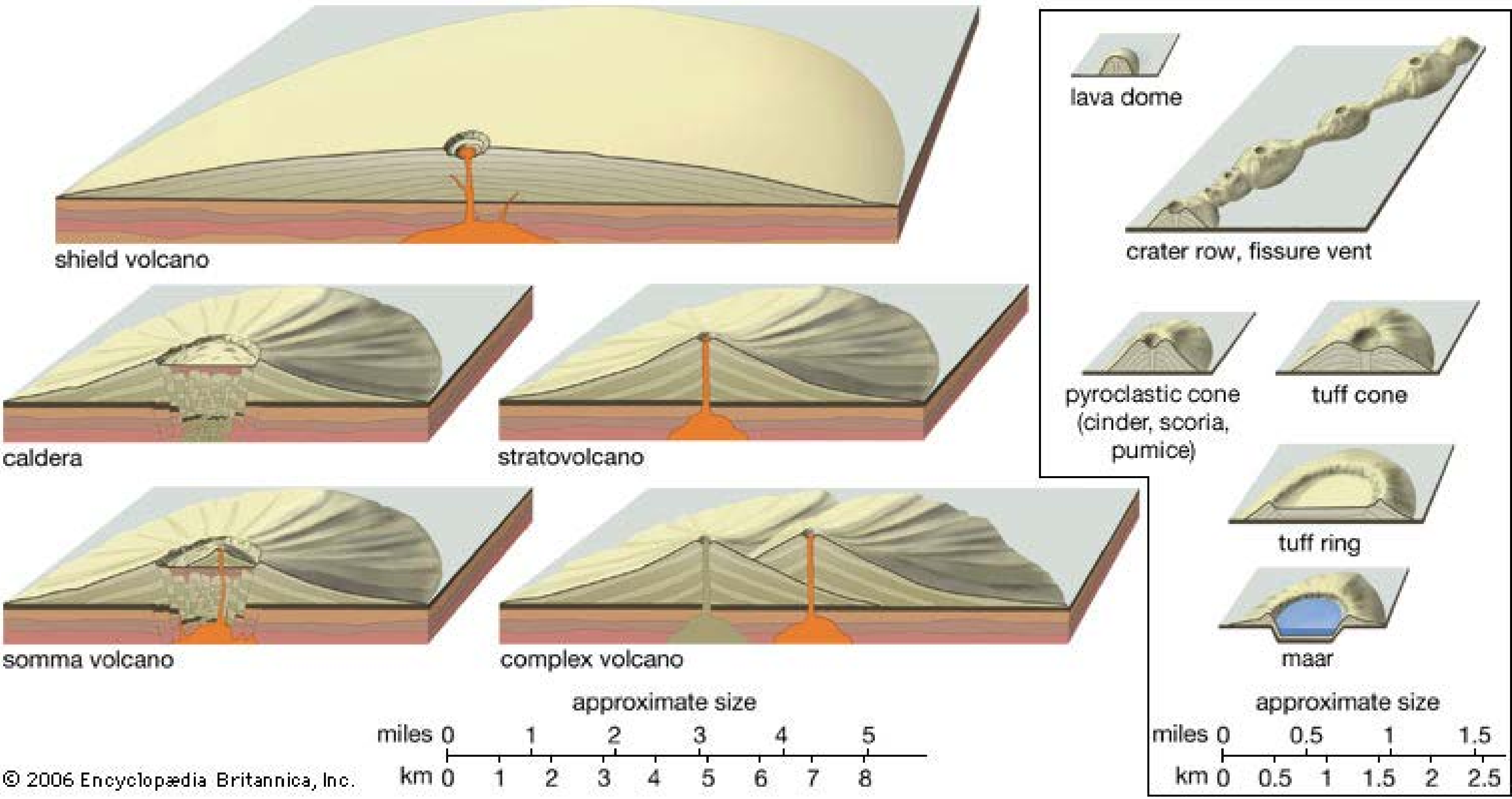


New Question:

What, actually, is a volcano?

What are other kinds of volcanoes?

Different Volcano Structures:



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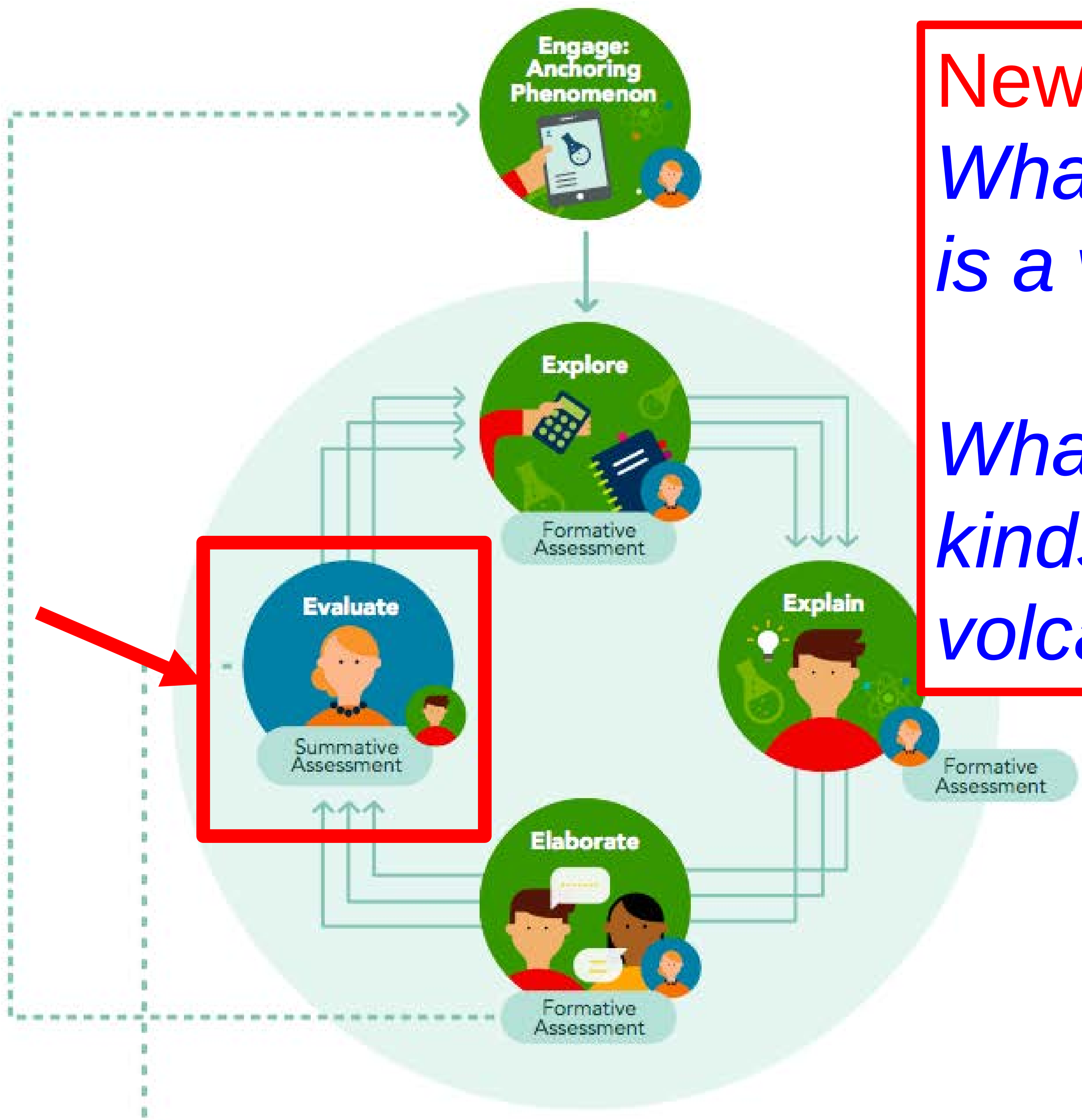
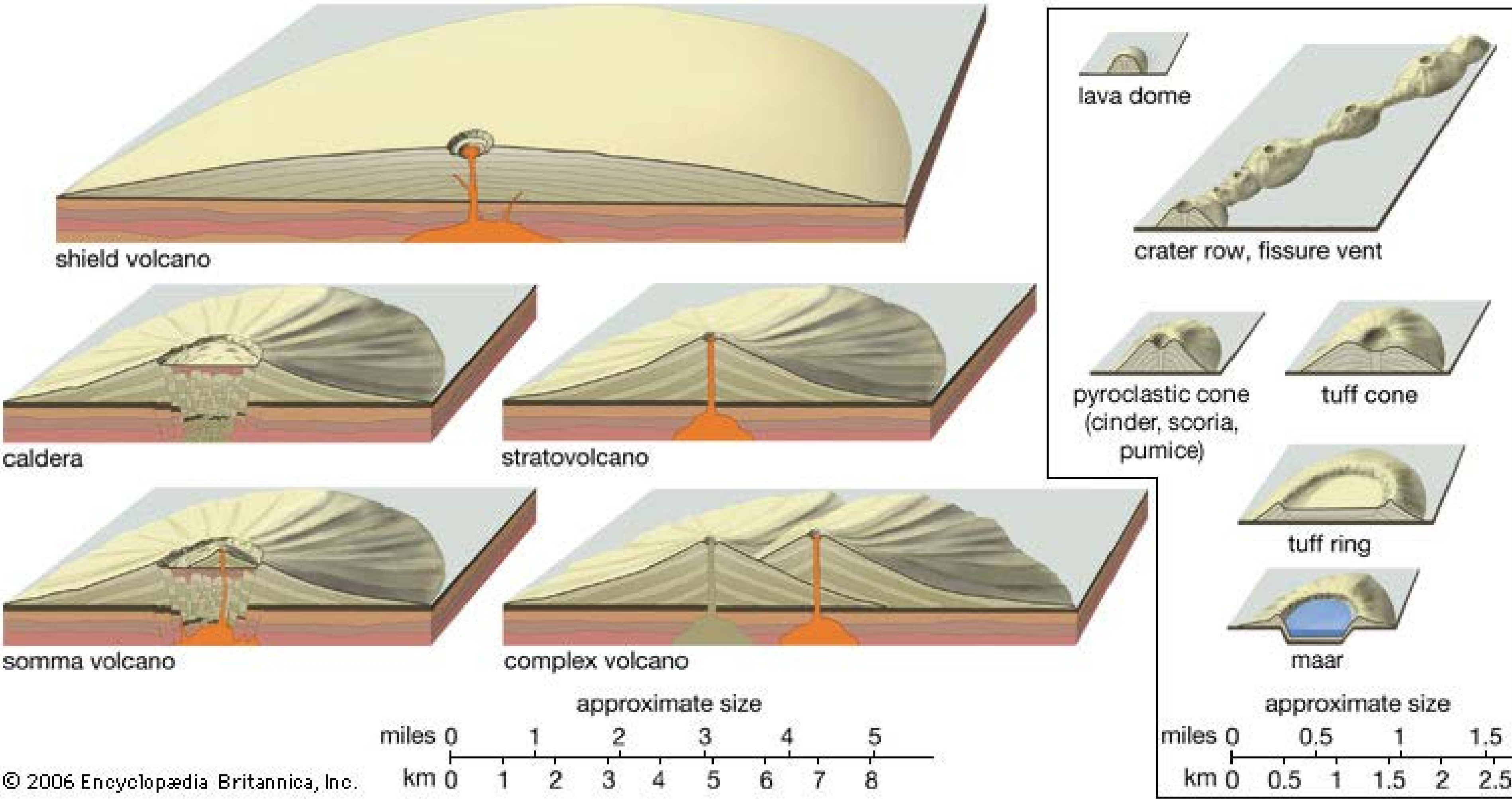


New Question:

What, actually, is a volcano?

What are other kinds of volcanoes?

New Question: *Wait….rock melts?! Why does rock melt?*



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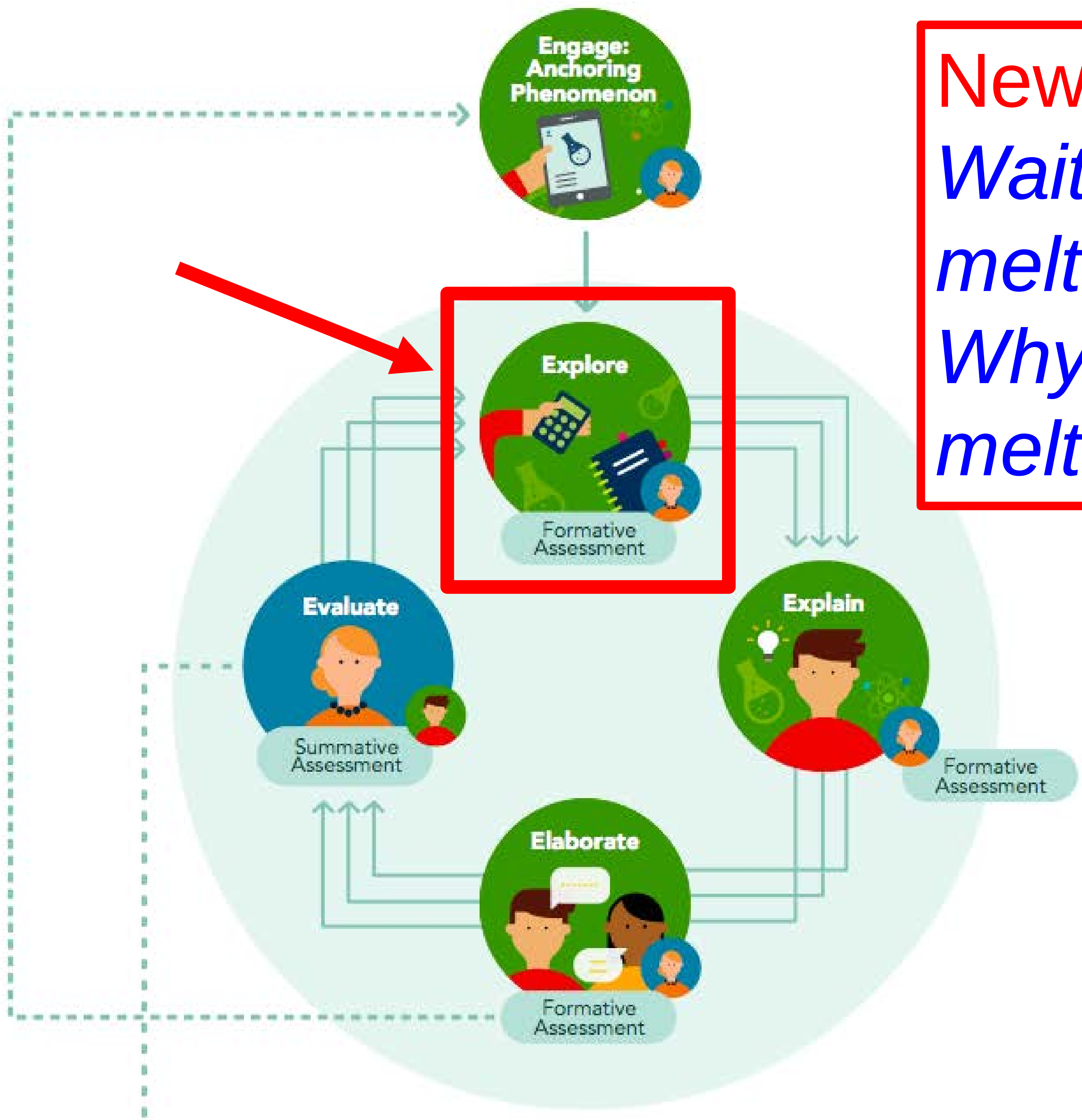
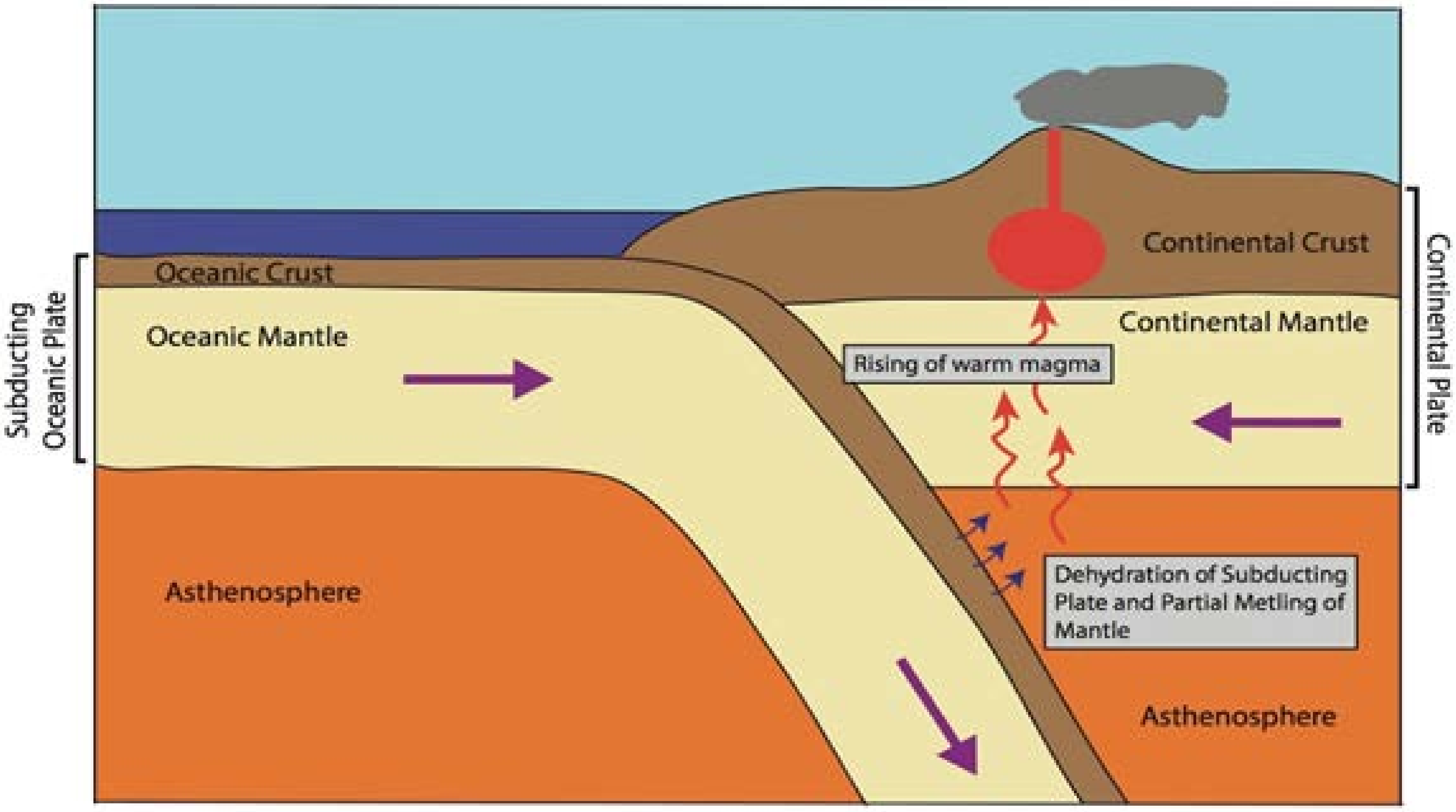


New Question:

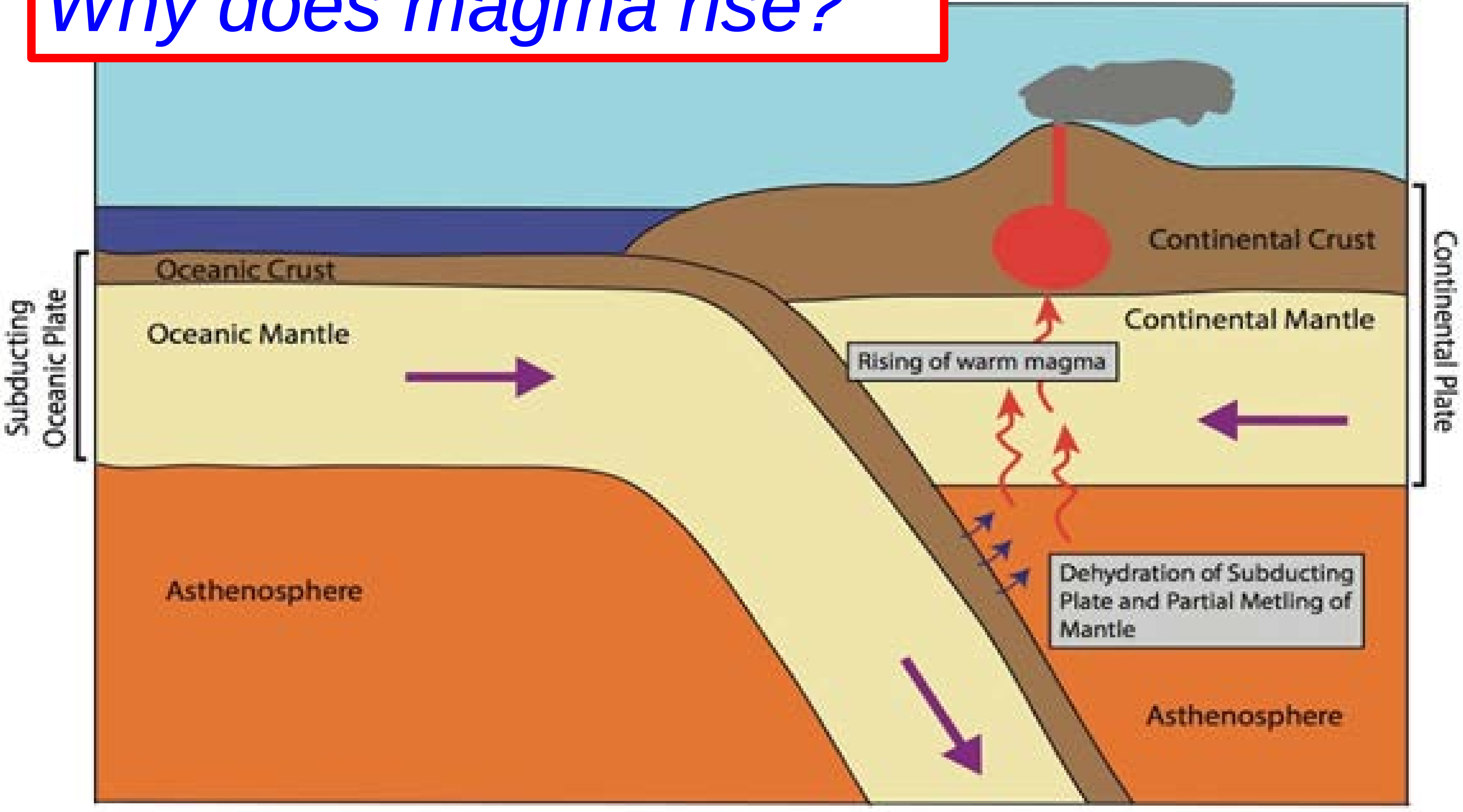
Wait…rock melts?!

Why does rock melt?


Continental Crust
Oceanic Crust
Continental Mantle
Oceanic Mantle
Subducting Oceanic Plate
Continental Plate
Rising of warm magma
Dehydration of Subducting Plate and Partial Metling of Mantle
Asthenosphere
Asthenosphere

New Question:

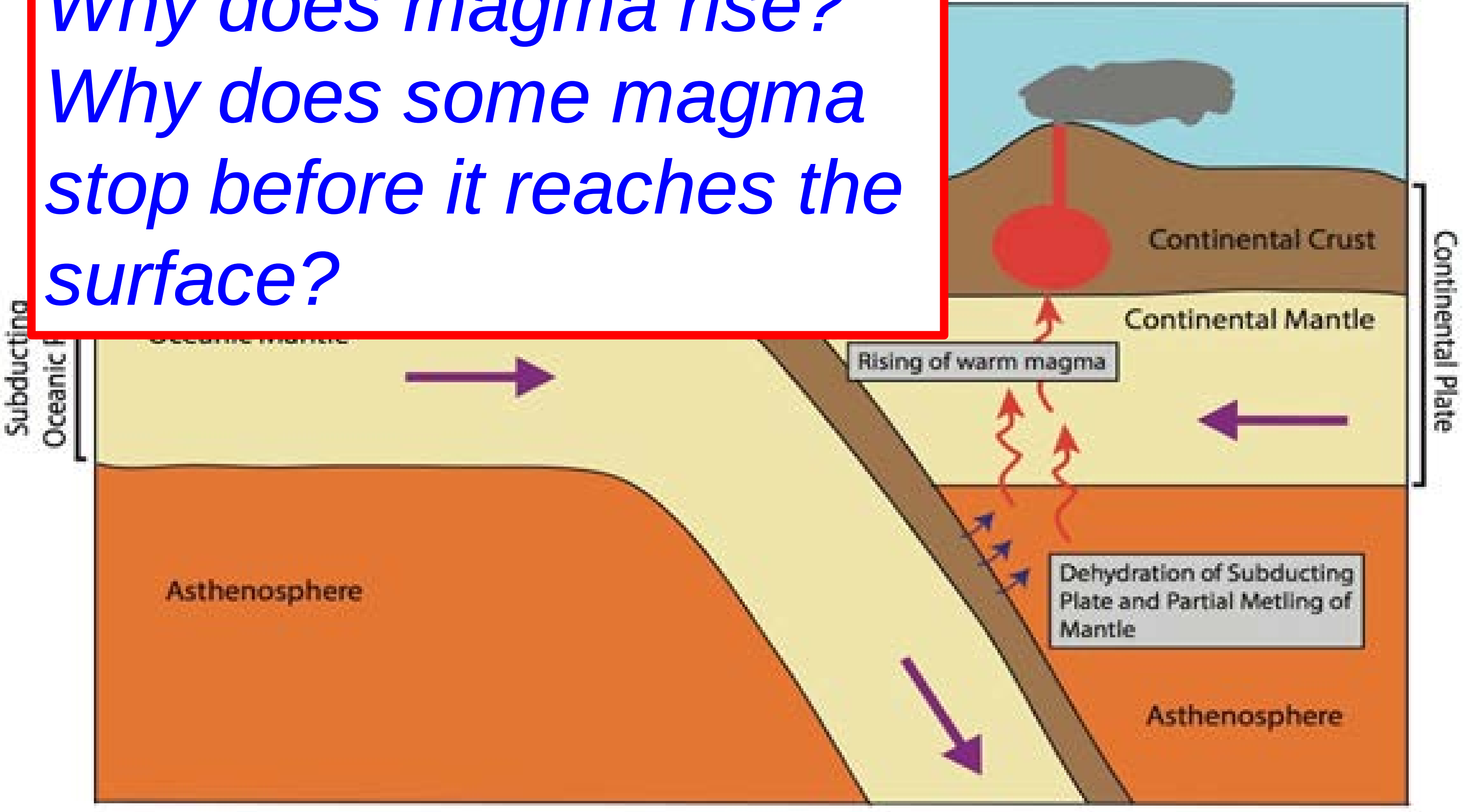
Why does magma rise?



New Question:

Why does magma rise?

Why does some magma stop before it reaches the surface?

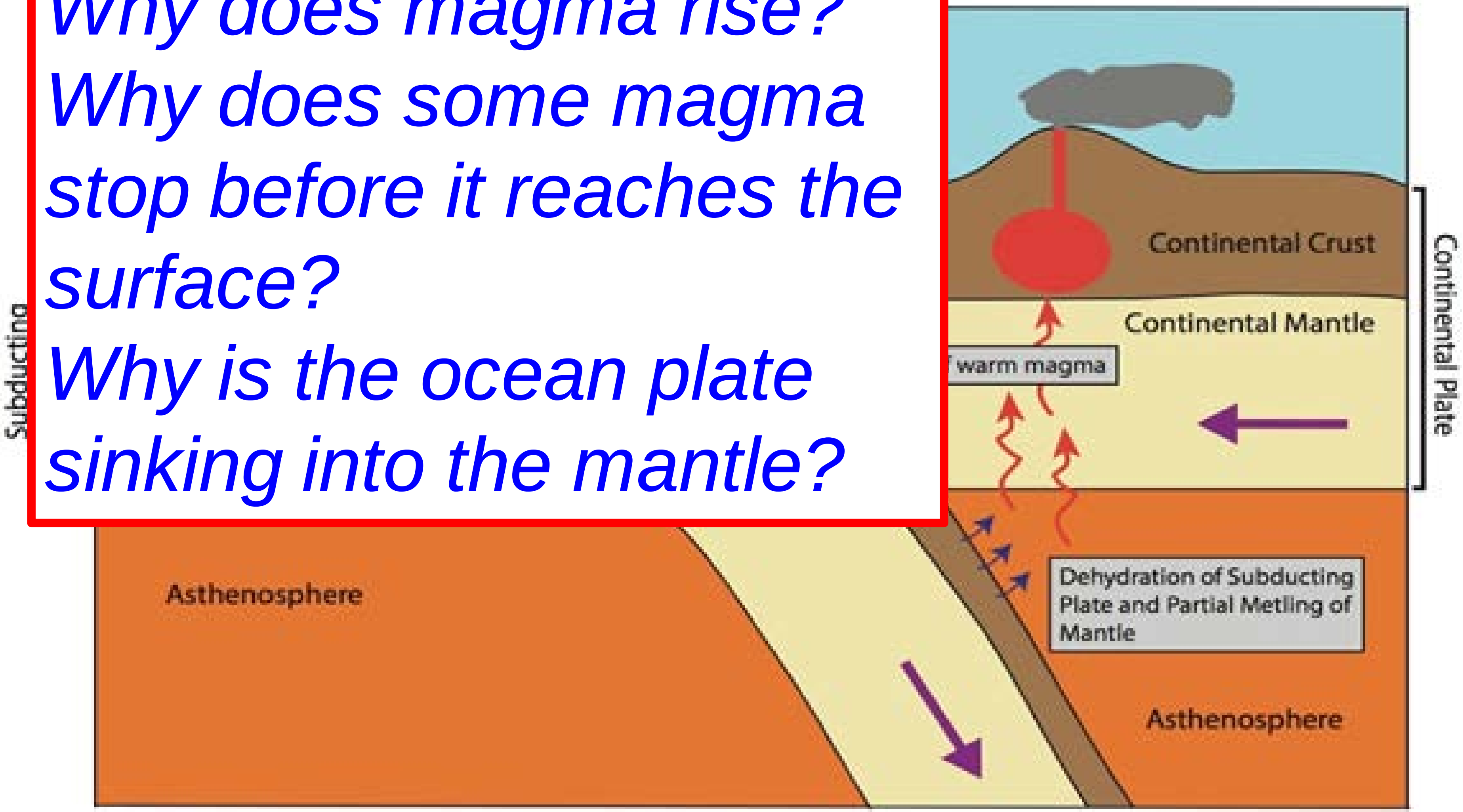


New Question:

Why does magma rise?

Why does some magma stop before it reaches the surface?

Why is the ocean plate sinking into the mantle?



New Question:

Why does magma rise?

Why does some magma stop before it reaches the surface?

Why is the ocean plate sinking into the mantle?

What's a "plate" or a "mantle?"

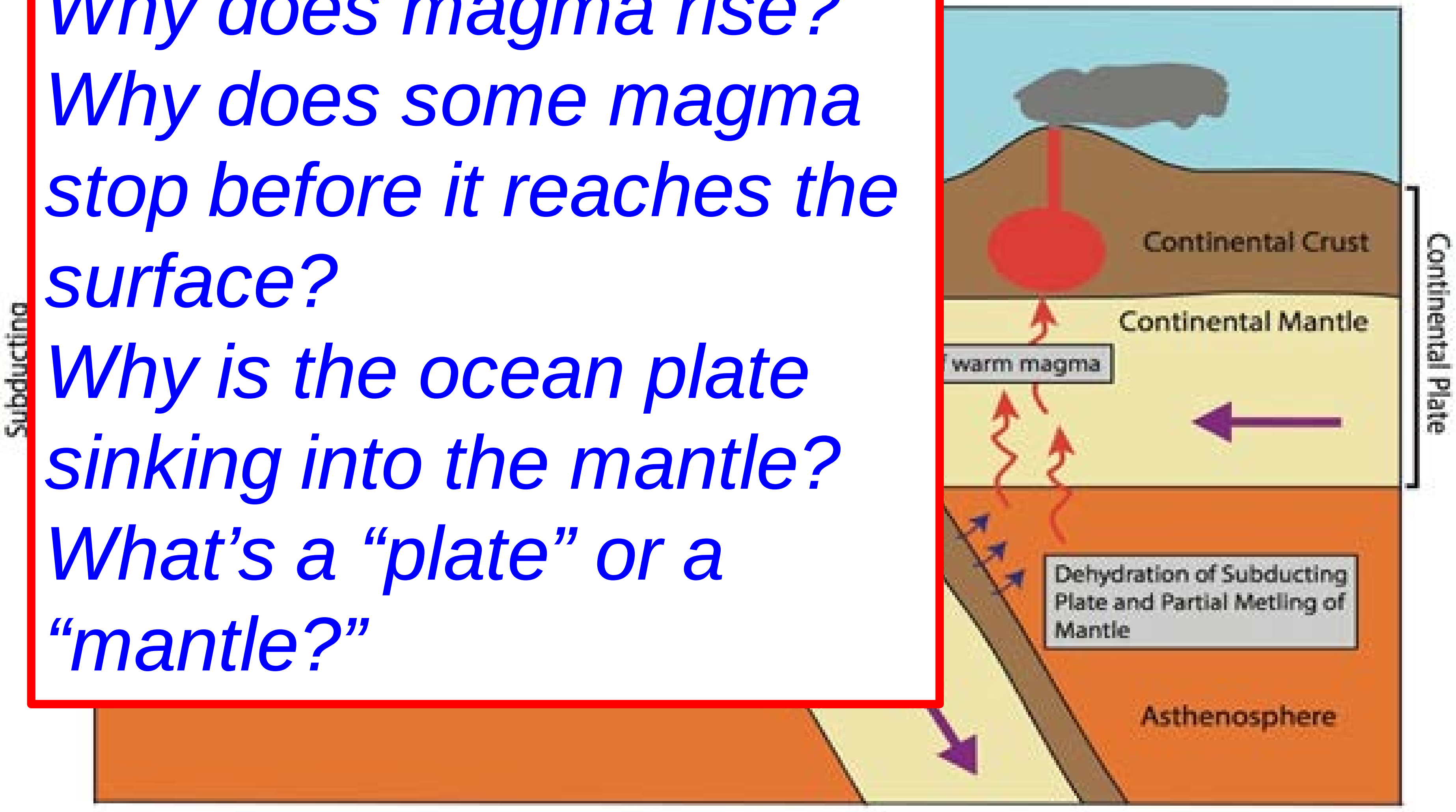


PLATE TECTONICS

Locations of the Major Tectonic "Plates"

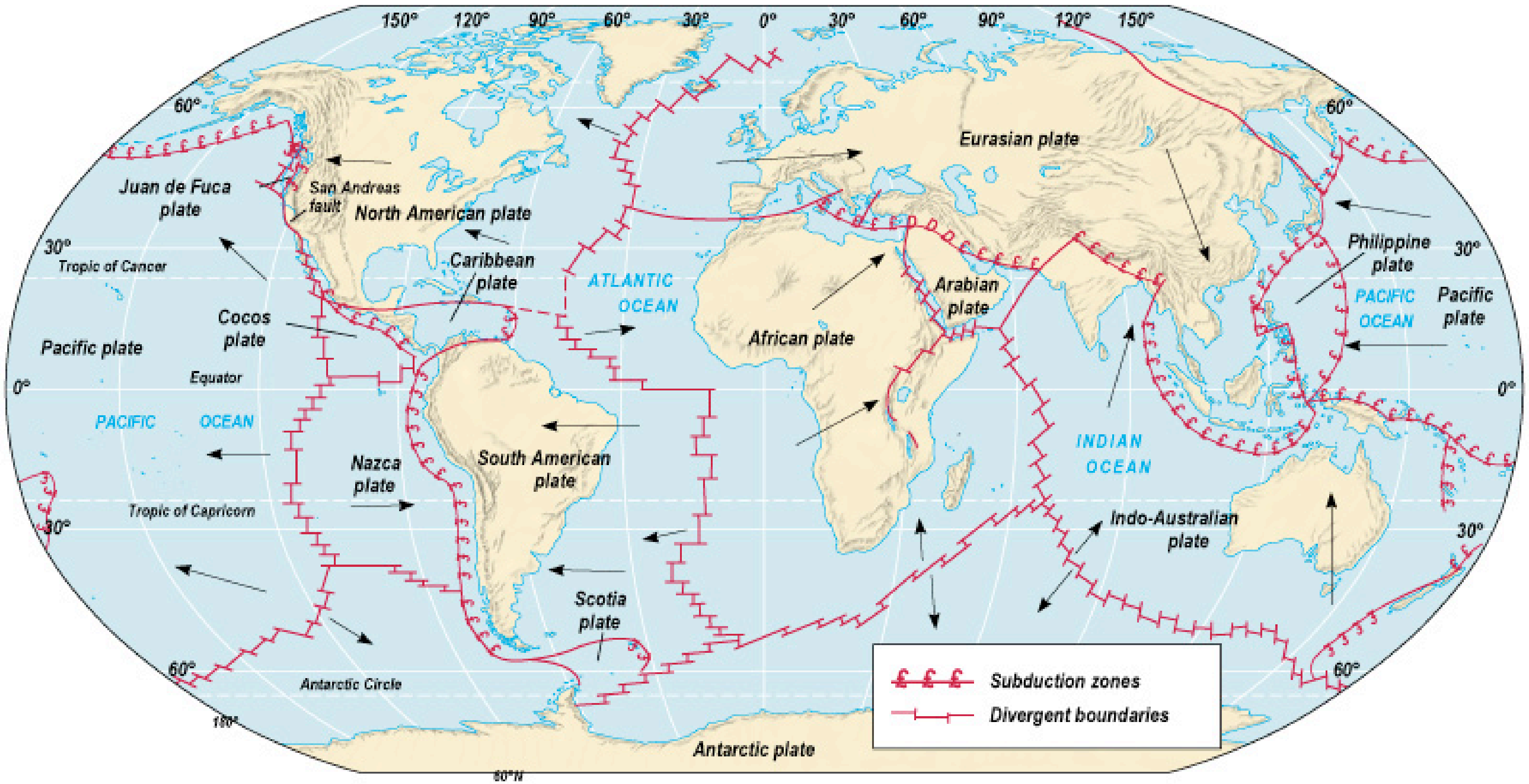


Plate Motion Vectors

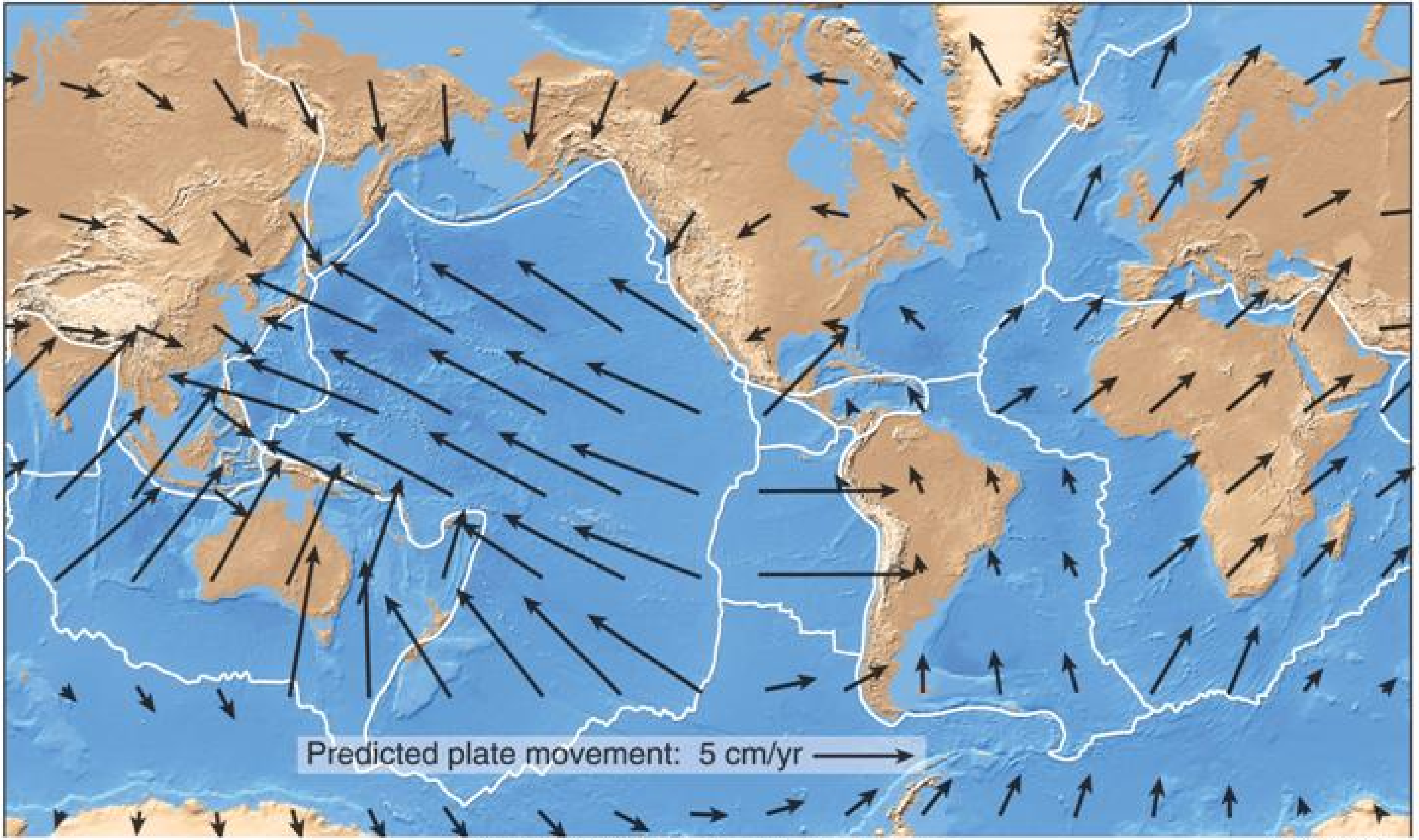
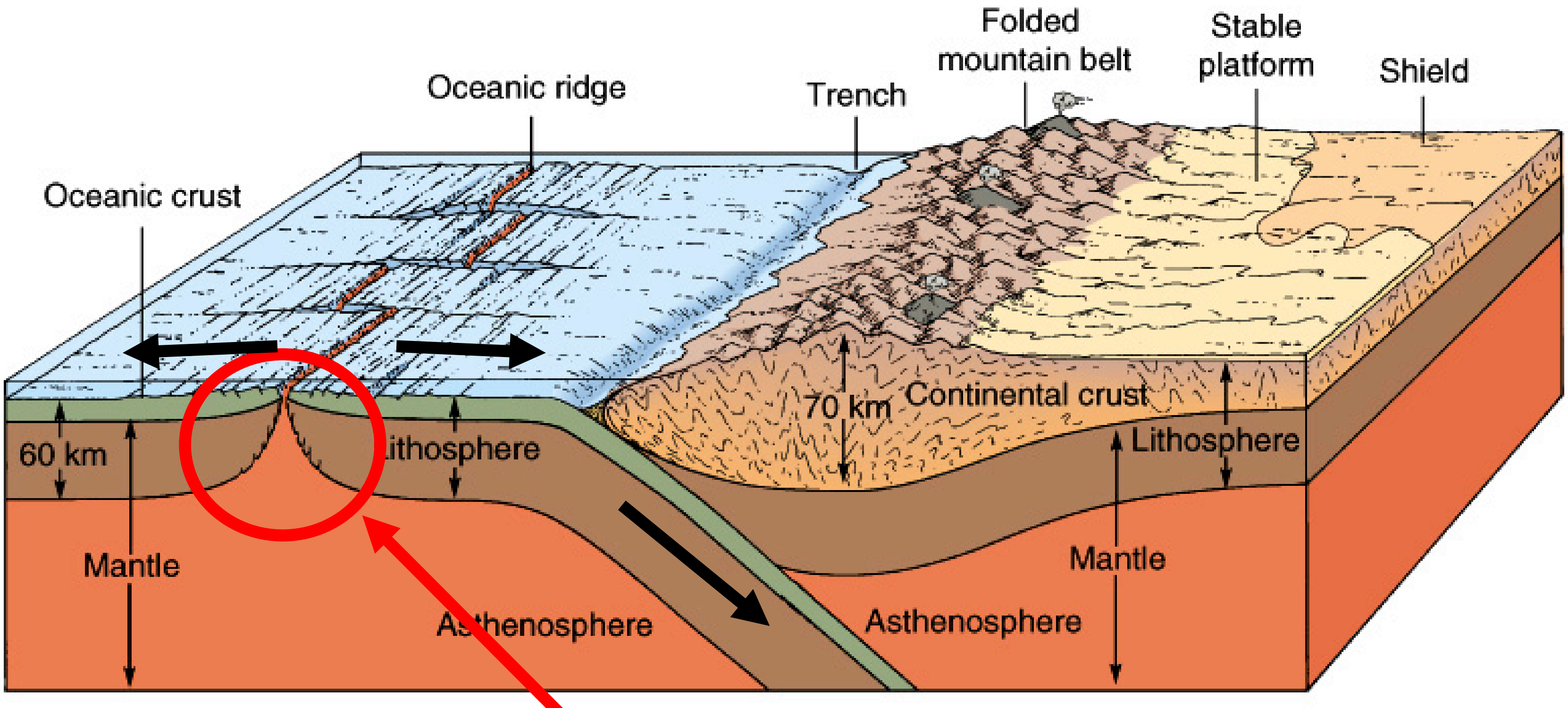
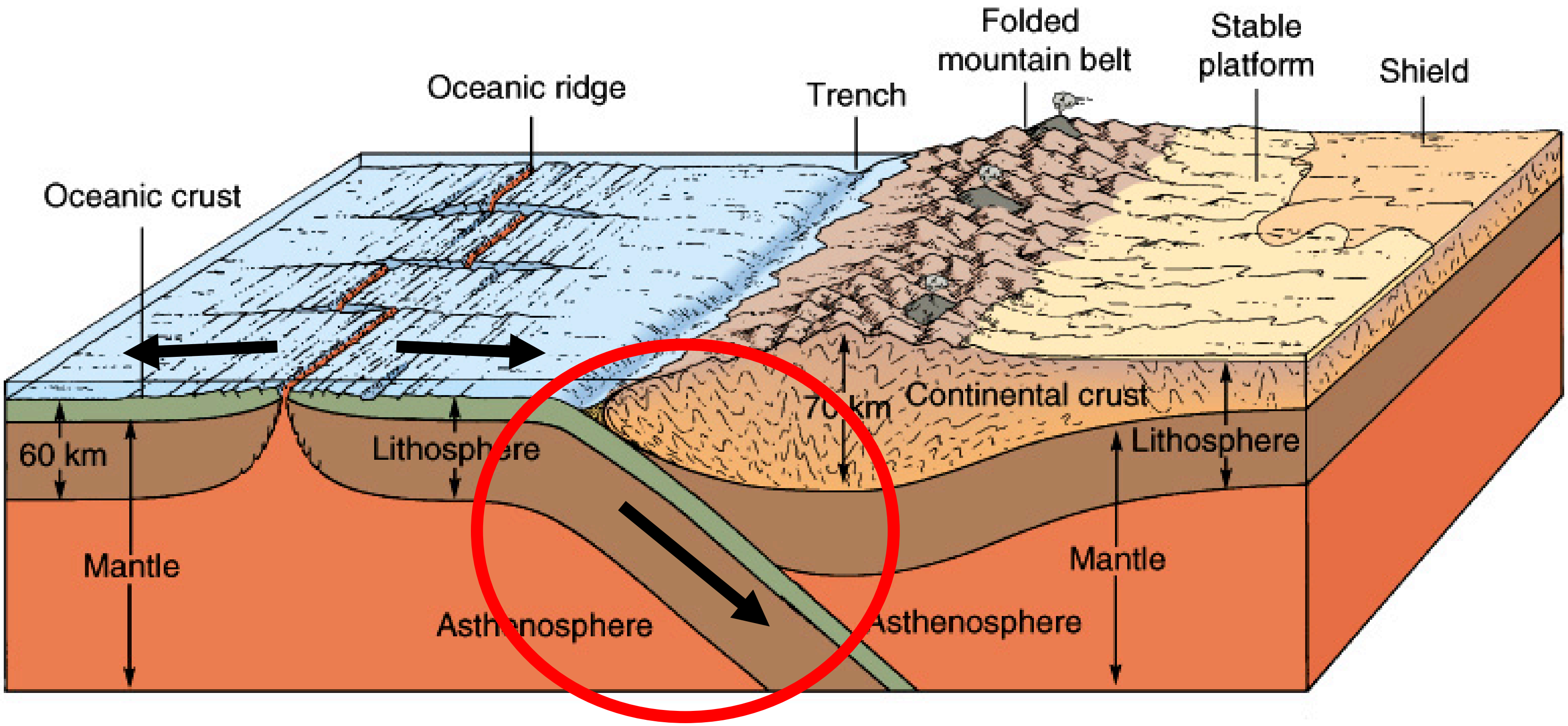


Plate Tectonics (*The Basic Idea*)



Mid-Ocean Ridge

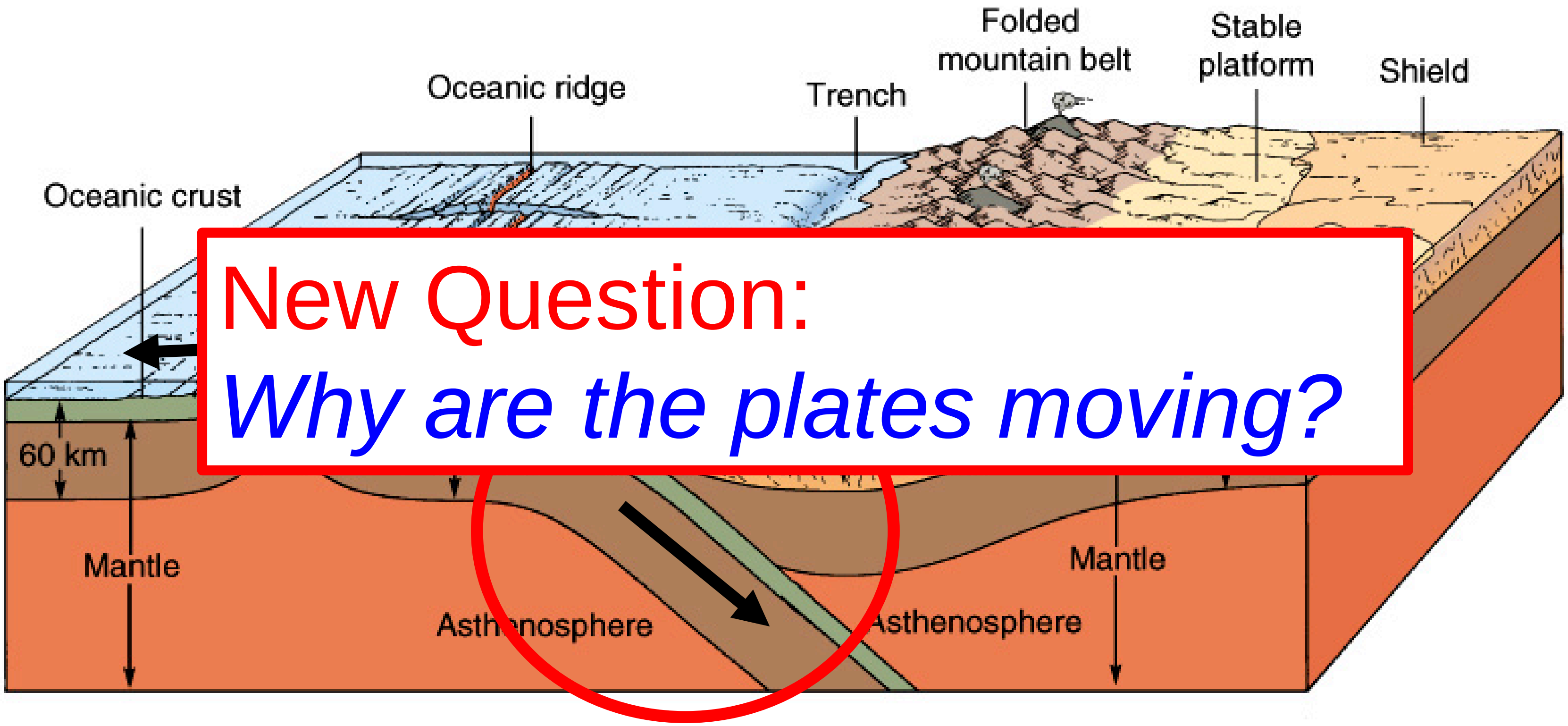
Plate Tectonics (*The Basic Idea*)



Subduction Zone

PLATE TECTONICS

Plate Tectonics (*The Basic Idea*)



New Question:

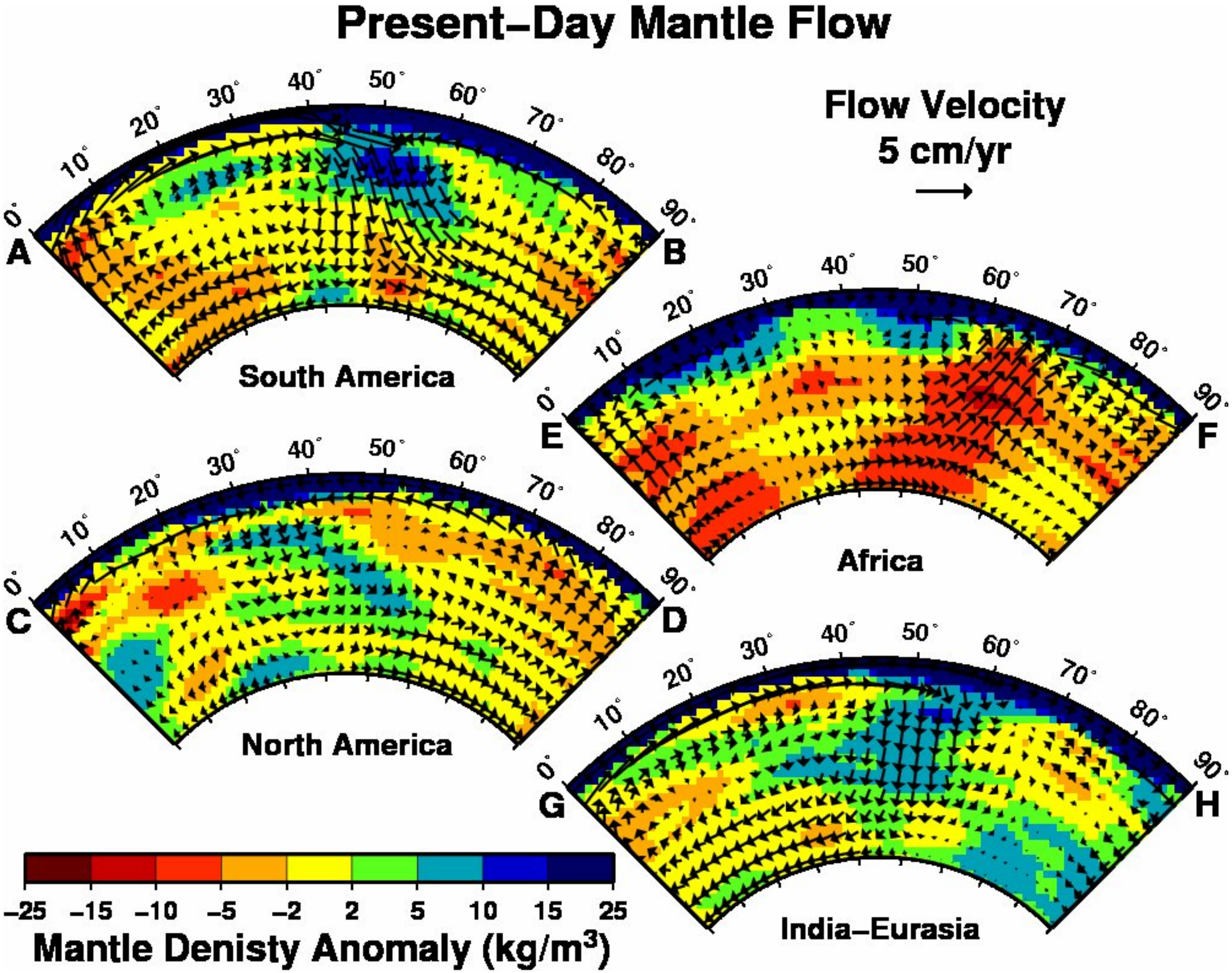
Why are the plates moving?

Subduction Zone

GLOBAL TOMOGRAPHY: MANTLE FLOW

Blue → Cold → Dense → Sinking

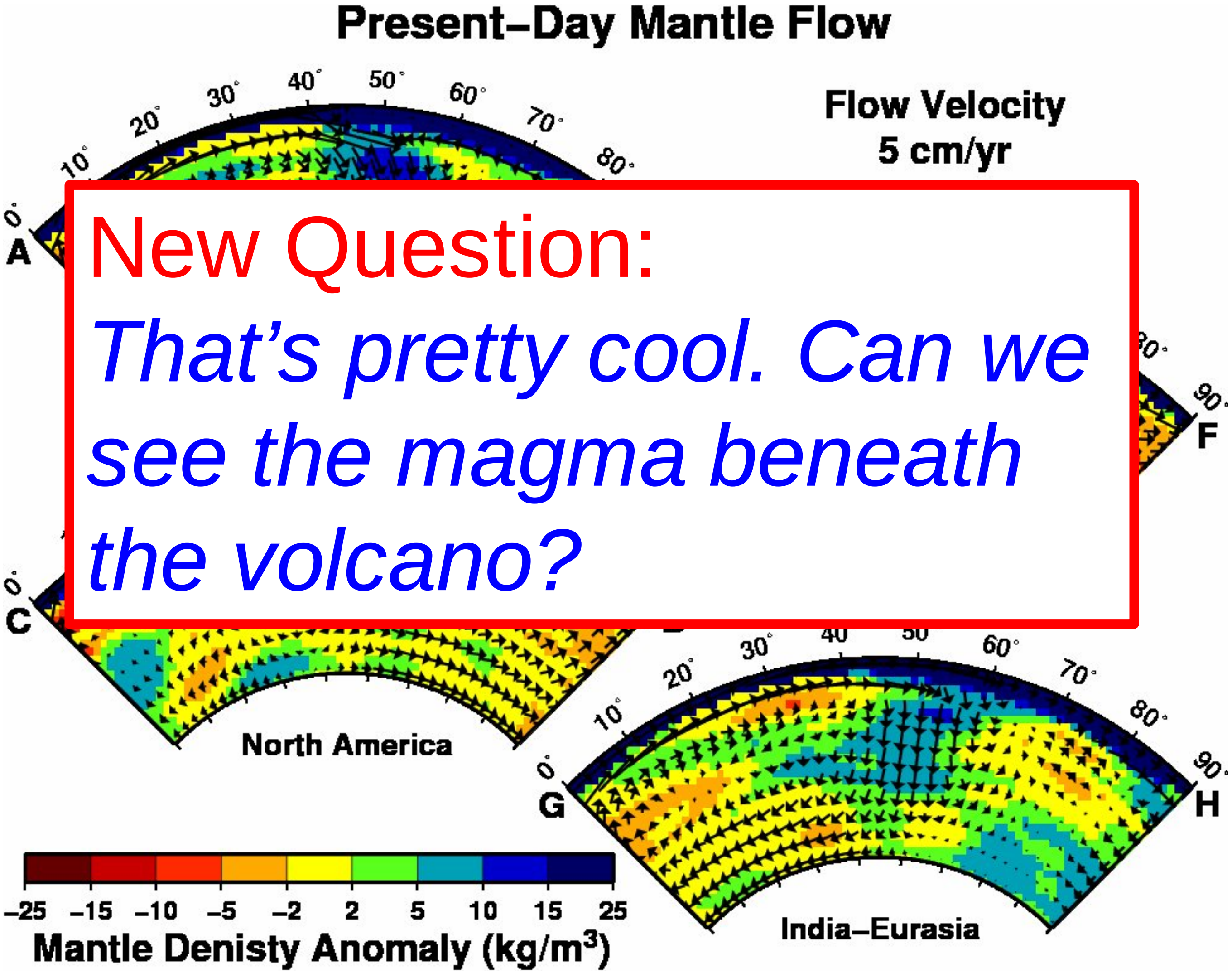
Red → Hot → Buoyant → Rising



GLOBAL TOMOGRAPHY: MANTLE FLOW

Blue → Cold → Dense → Sinking

Red → Hot → Buoyant → Rising

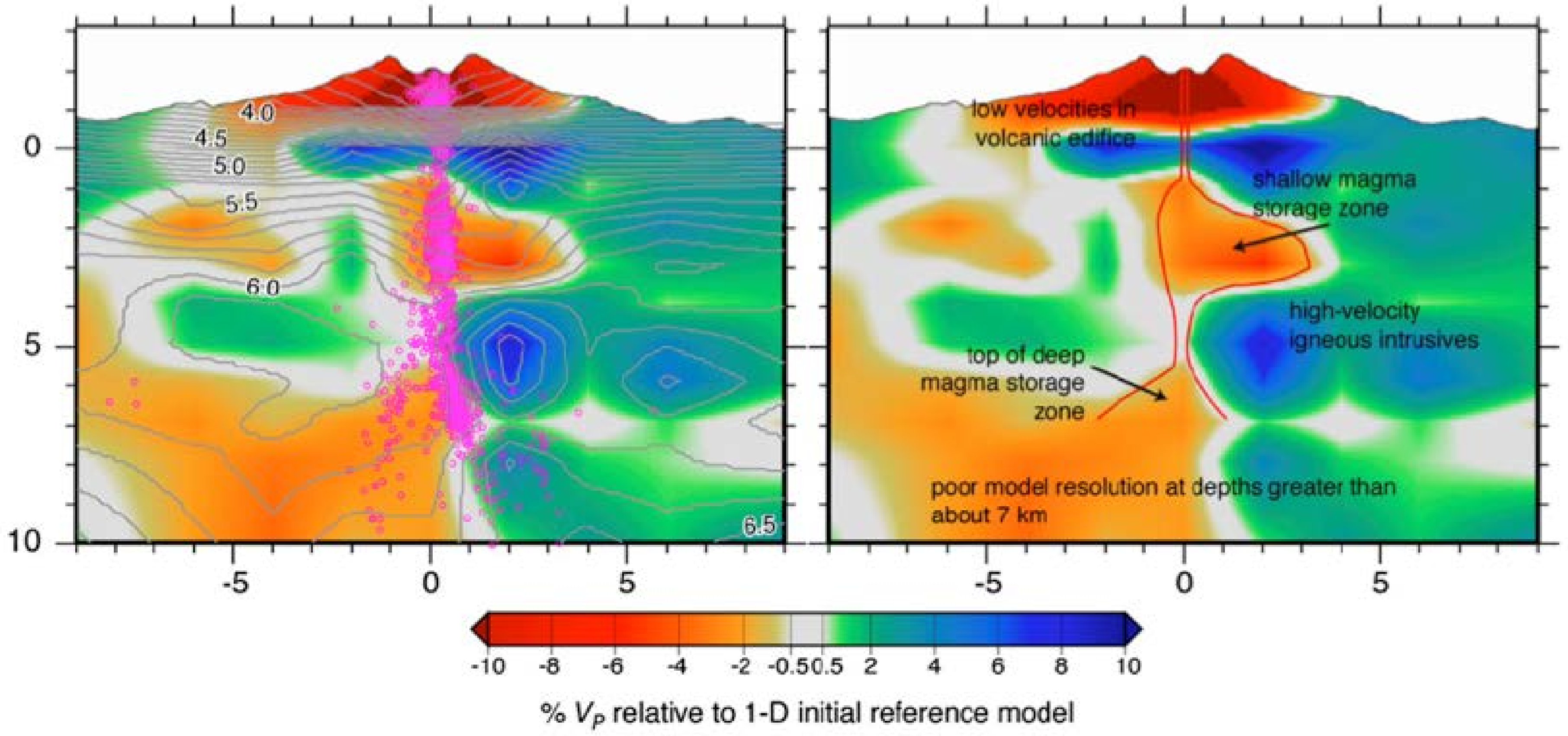


New Question:

That's pretty cool. Can we see the magma beneath the volcano?

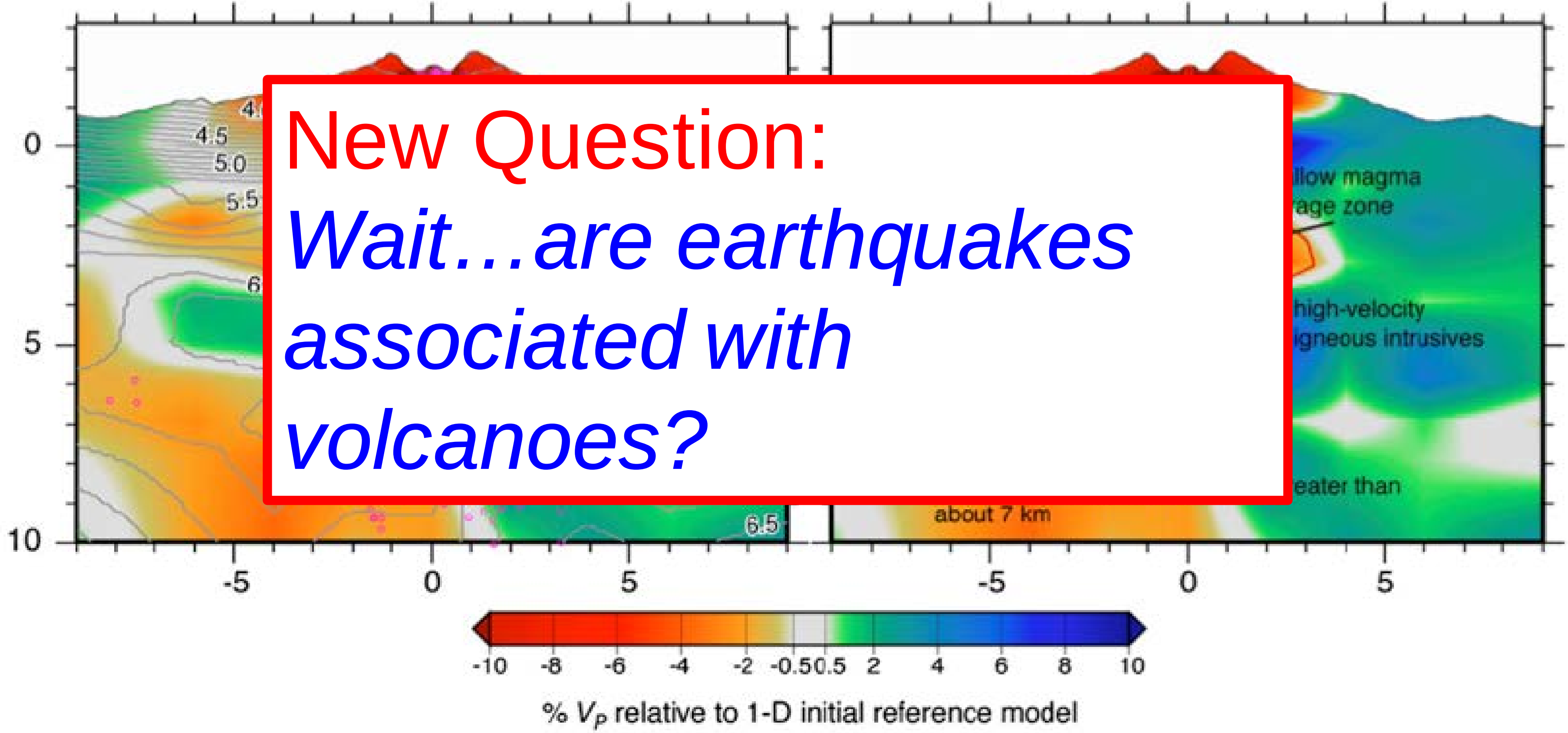
SEISMIC BODY WAVE TOMOGRAPHY

Mt. St. Helens Magma Chamber



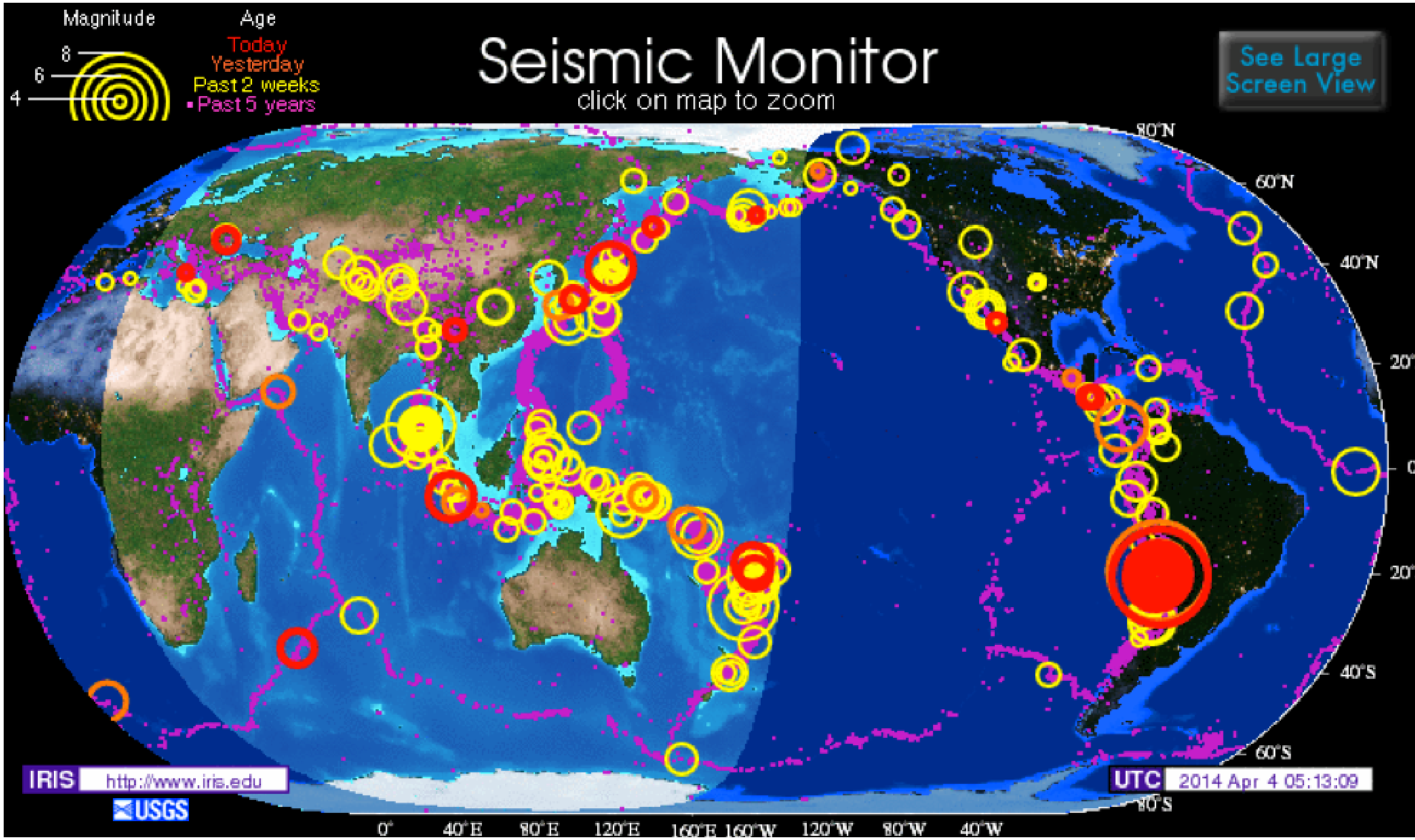
SEISMIC BODY WAVE TOMOGRAPHY

Mt. St. Helens Magma Chamber



New Question:

Wait…are earthquakes associated with volcanoes?

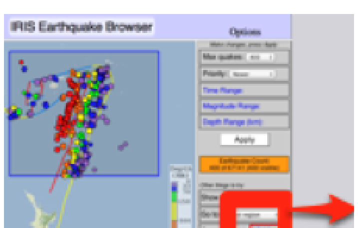


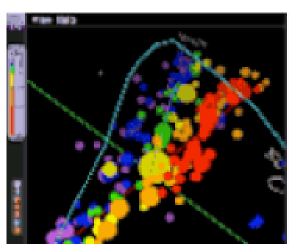
Longitude -215 W Latitude 90 S

Help | Earthquake Headlines | Last 30 Days Earthquakes | Special Events | Plate Tectonics | Education Links

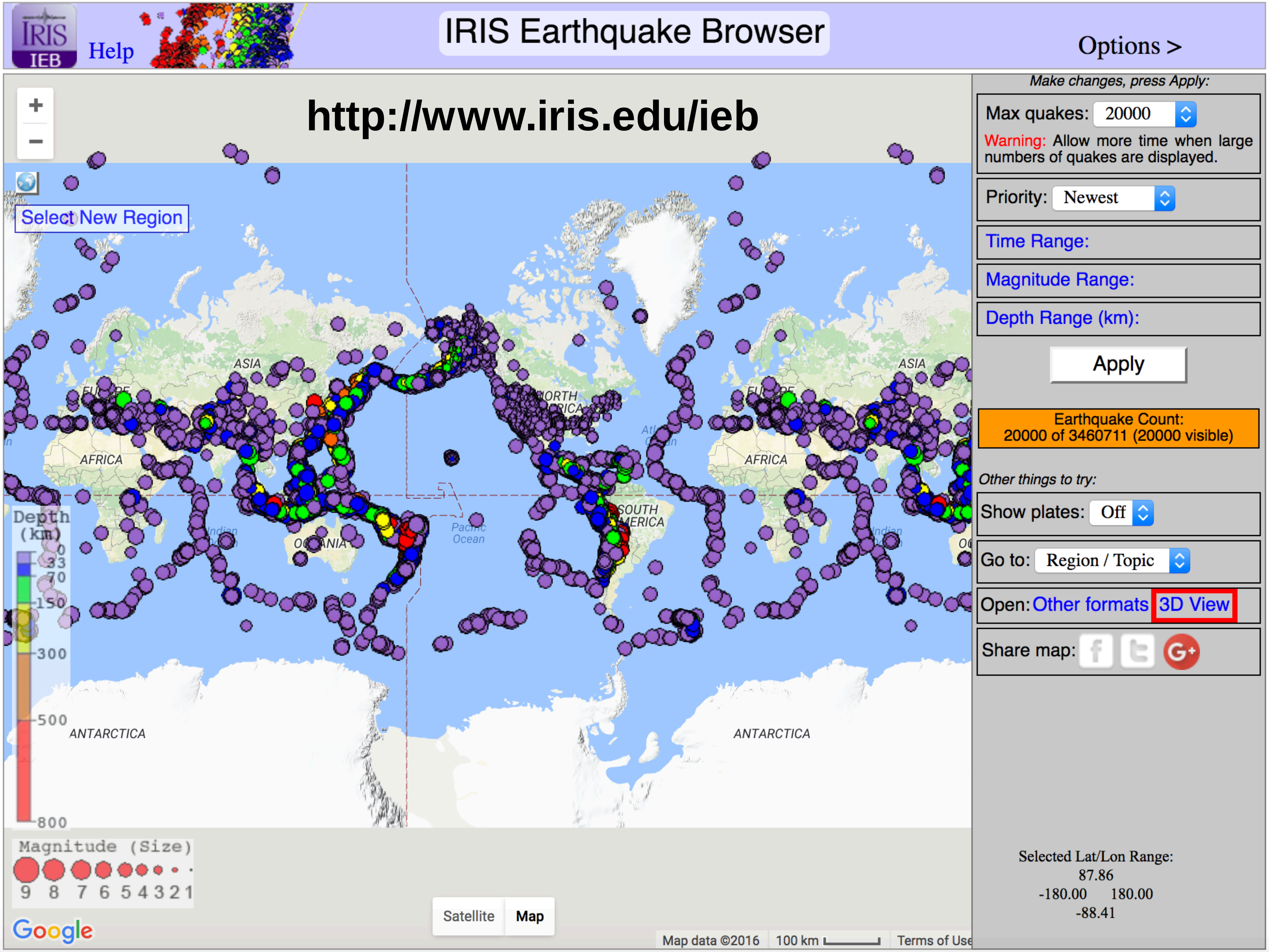
New: Earthquake browser with 3D viewer! *Nuevo: Navegador de Terremotos con Vista 3D!* *y Boletines en español*

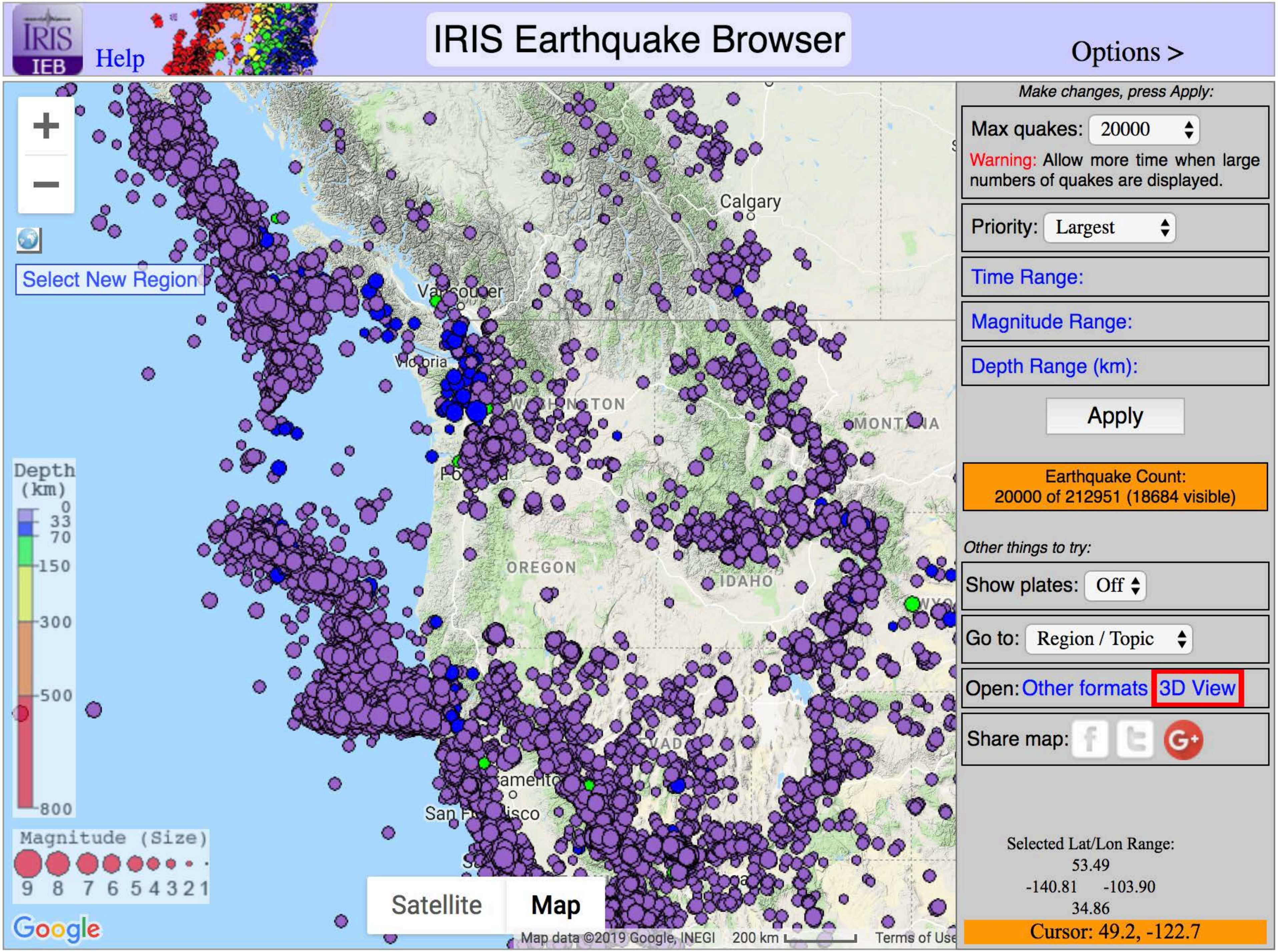
IEB is a new, interactive map that not only shows the latest earthquakes but allows you to display thousands of quakes from an archive of 3.4 million spanning from 1970 to minutes ago. It's the *IRIS Earthquake Browser*, or just IEB, and one of many features is that you can rotate quakes in 3D! (No Flash or Java used)

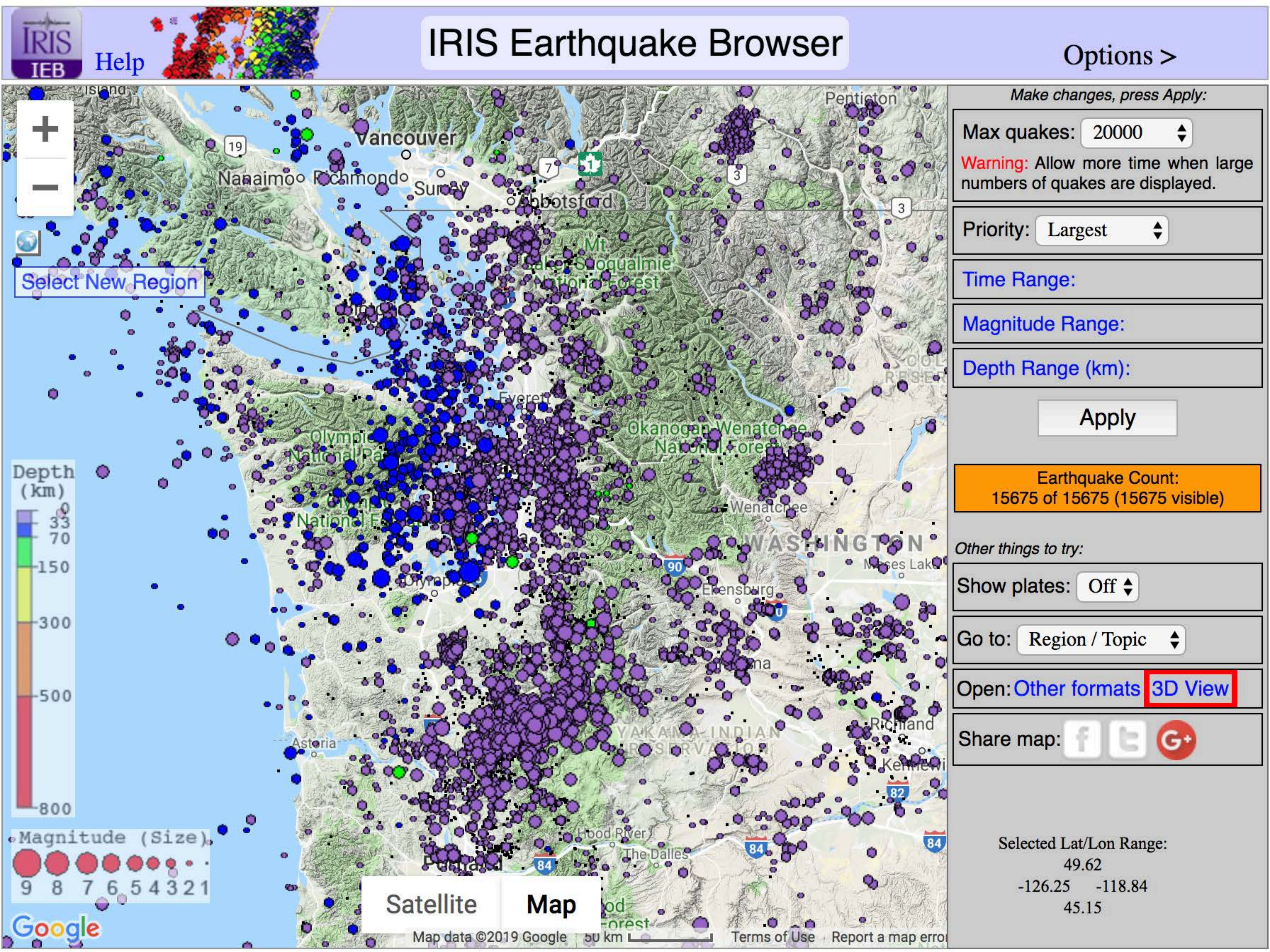


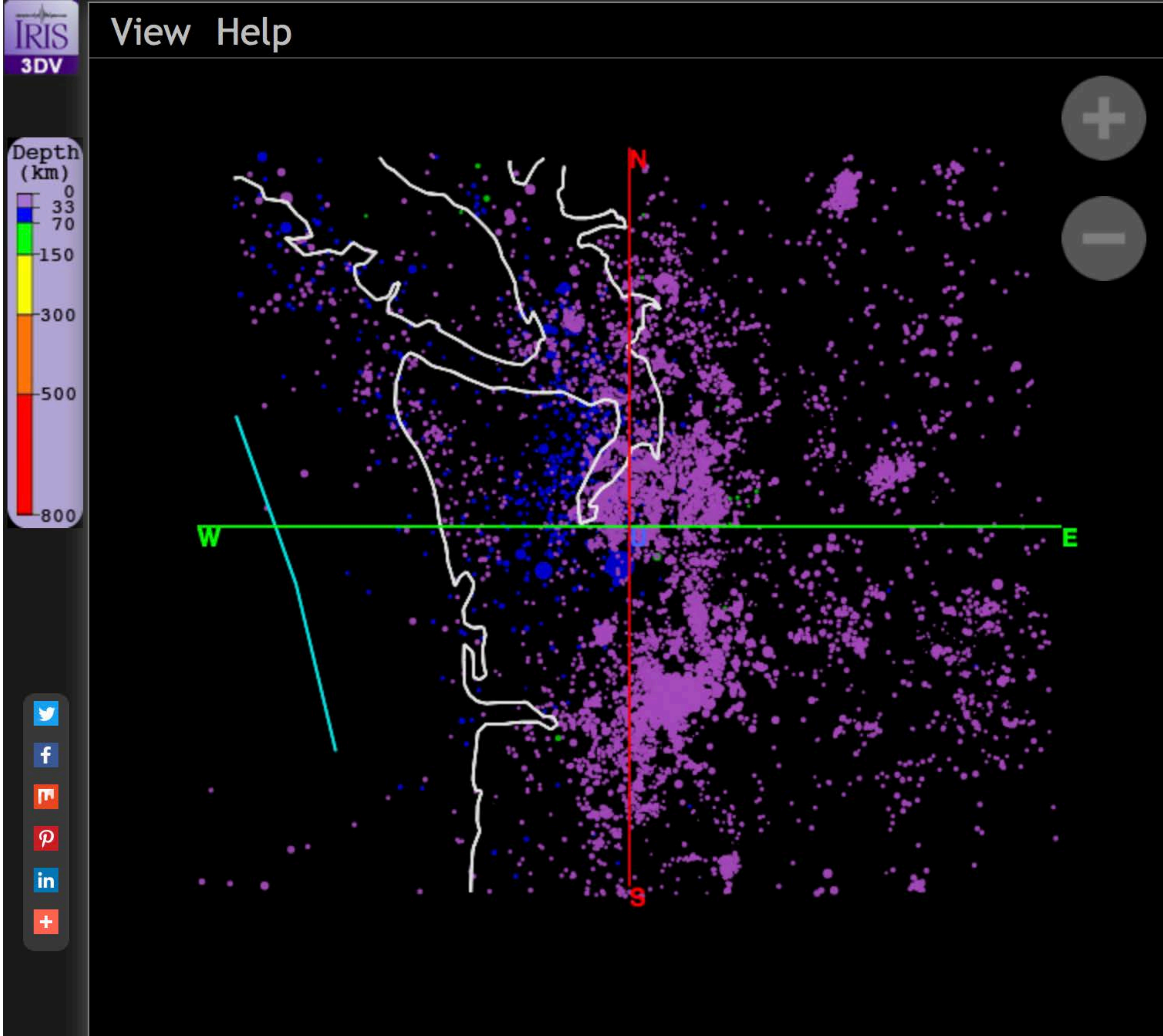


www.iris.edu


IRIS IEB
Help
IRIS Earthquake Browser
Options >
http://www.iris.edu/ieb
Select New Region
ASIA
EUROPE
AFRICA
OCEANIA
NORTH AMERICA
SOUTH AMERICA
Pacific Ocean
Indian Ocean
Atlantic Ocean
ANTARCTICA
Depth (km)
0
33
70
150
300
500
800
Magnitude (Size)
9 8 7 6 5 4 3 2 1
Satellite
Map
Google
Map data ©2016
100 km
Terms of Use
Make changes, press Apply:
Max quakes: 20000
Warning: Allow more time when large numbers of quakes are displayed.
Priority: Newest
Time Range:
Magnitude Range:
Depth Range (km):
Apply
Earthquake Count:
20000 of 3460711 (20000 visible)
Other things to try:
Show plates: Off
Go to: Region / Topic
Open: Other formats 3D View
Share map:
Selected Lat/Lon Range:
87.86
-180.00 180.00
-88.41


IRIS
IEB
Help
IRIS Earthquake Browser
Options >
Select New Region
Calgary
Vancouver
Victoria
WASHINGTON
MONTANA
OREGON
IDAHO
San Francisco
Depth (km)
0
33
70
150
300
500
800
Magnitude (Size)
9 8 7 6 5 4 3 2 1
Satellite
Map
Map data ©2019 Google, INEGI
200 km
Terms of Use
Make changes, press Apply:
Max quakes: 20000
Warning: Allow more time when large numbers of quakes are displayed.
Priority: Largest
Time Range:
Magnitude Range:
Depth Range (km):
Apply
Earthquake Count:
20000 of 212951 (18684 visible)
Other things to try:
Show plates: Off
Go to: Region / Topic
Open: Other formats 3D View
Share map:
Selected Lat/Lon Range:
53.49
-140.81 -103.90
34.86
Cursor: 49.2, -122.7


IRIS Earthquake Browser
Help
Options >
Select New Region
Depth (km)
0
33
70
150
300
500
800
Magnitude (Size)
9 8 7 6 5 4 3 2 1
Make changes, press Apply:
Max quakes: 20000
Warning: Allow more time when large numbers of quakes are displayed.
Priority: Largest
Time Range:
Magnitude Range:
Depth Range (km):
Apply
Earthquake Count:
15675 of 15675 (15675 visible)
Other things to try:
Show plates: Off
Go to: Region / Topic
Open: Other formats 3D View
Share map:
Selected Lat/Lon Range:
49.62
-126.25 -118.84
45.15
Satellite
Map
Map data ©2019 Google
50 km
Terms of Use
Vancouver
Nanaimo
Richmond
Surrey
Abbotsford
Penticton
Everett
Wenatchee
WASHINGTON
Ellensburg
Richland
Astoria
Hood River
The Dalles


IRIS
3DV
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Help
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(km)
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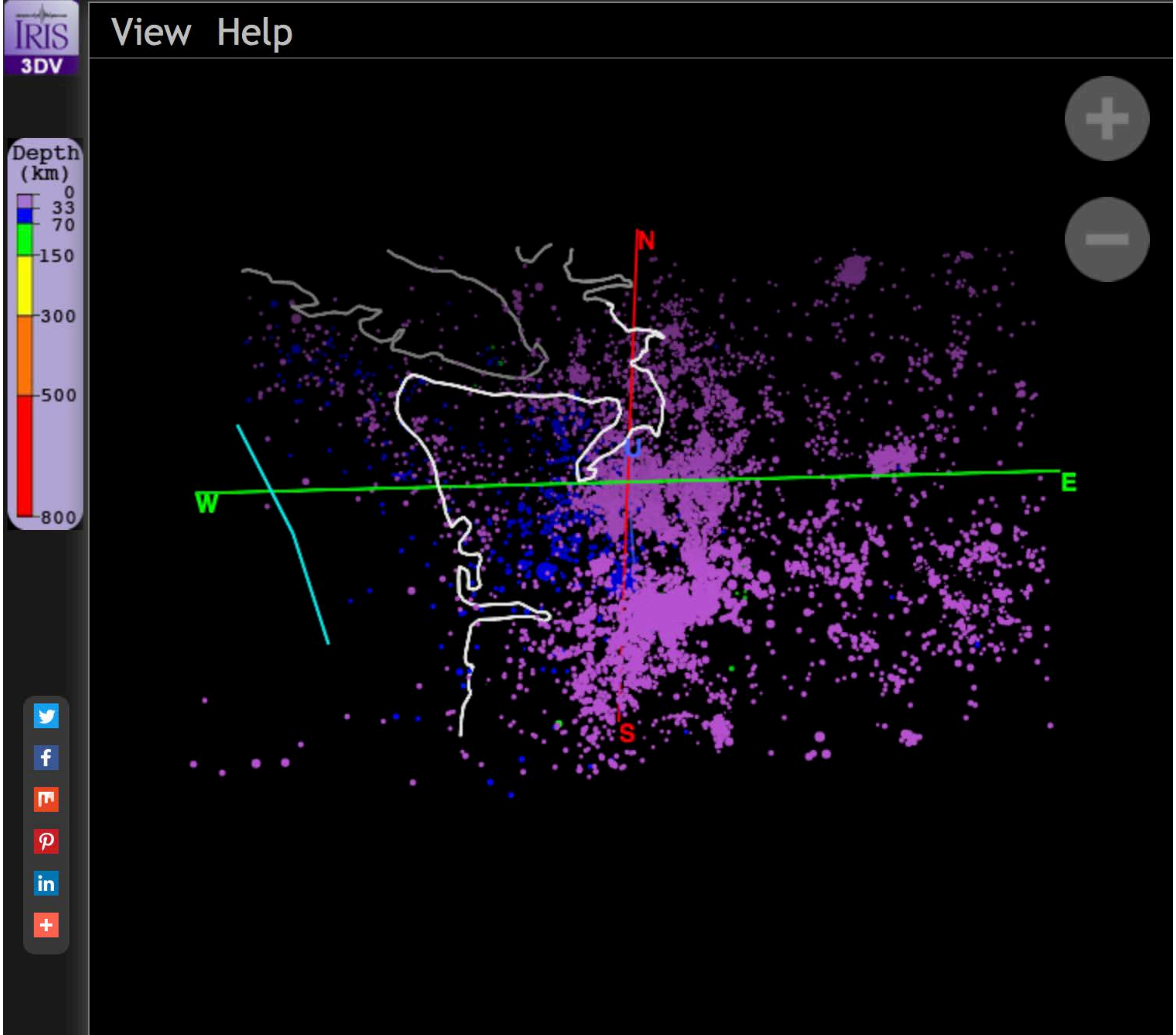
IRIS
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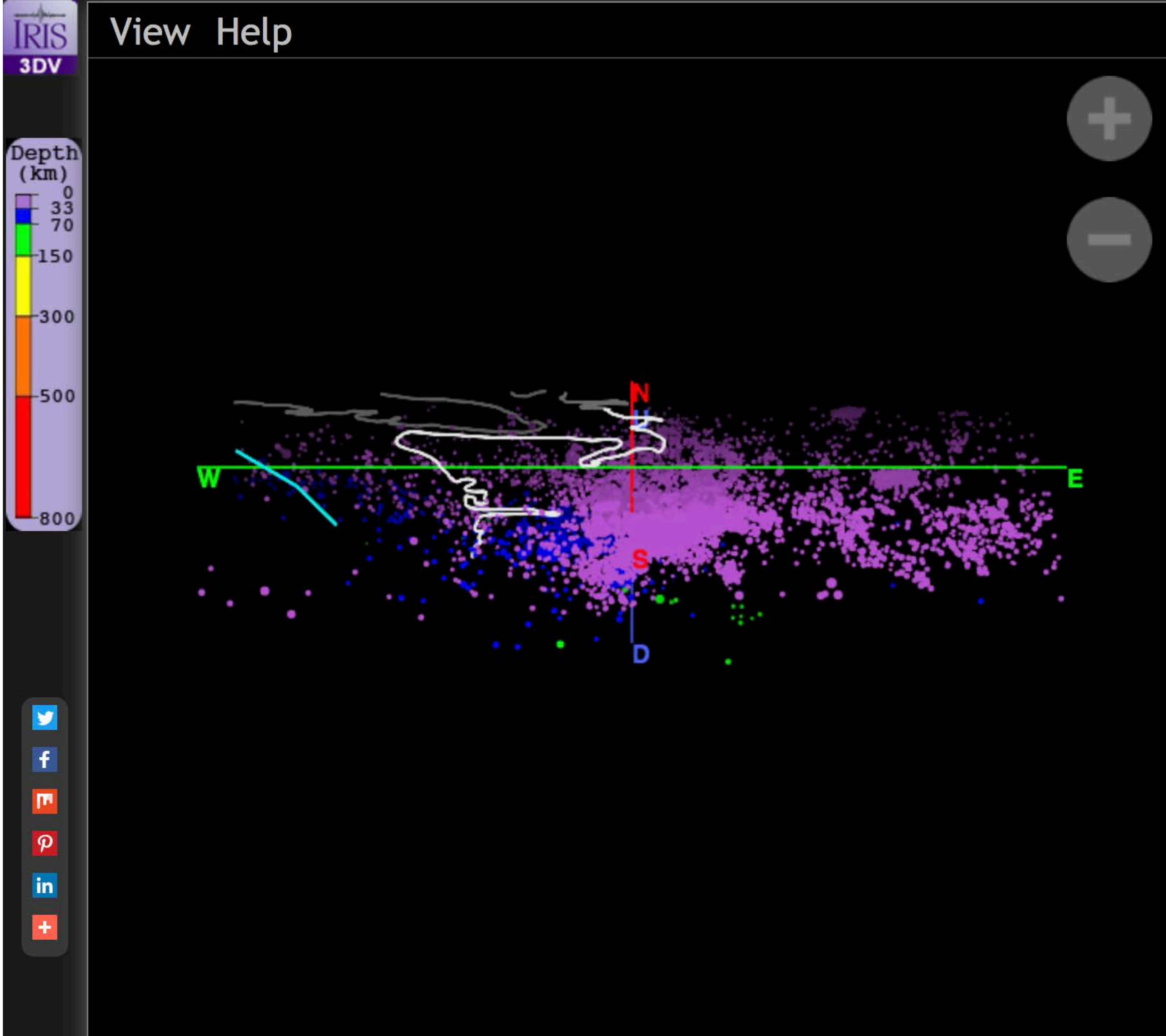
IRIS
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(km)
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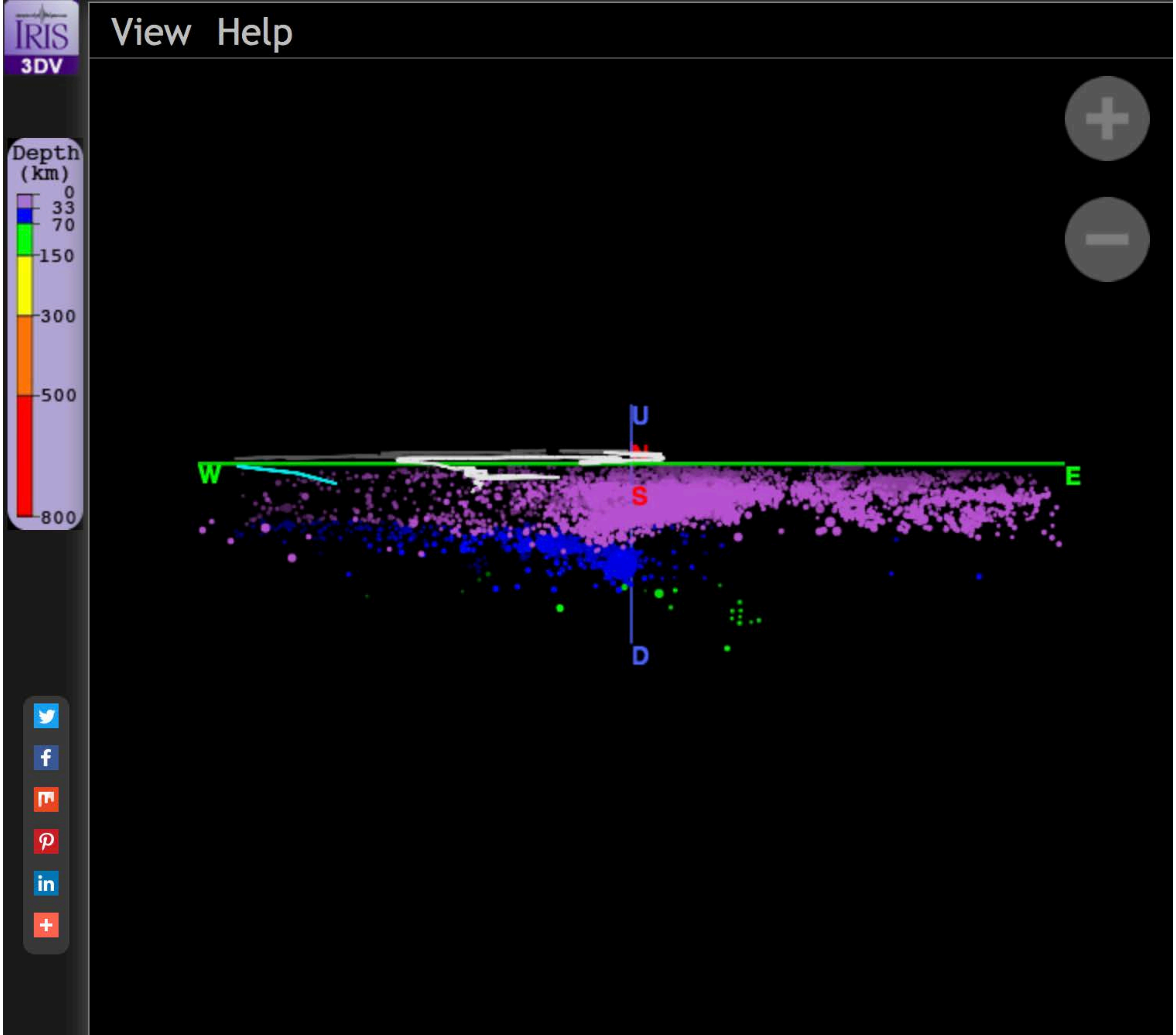
IRIS
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Help
Depth (km)
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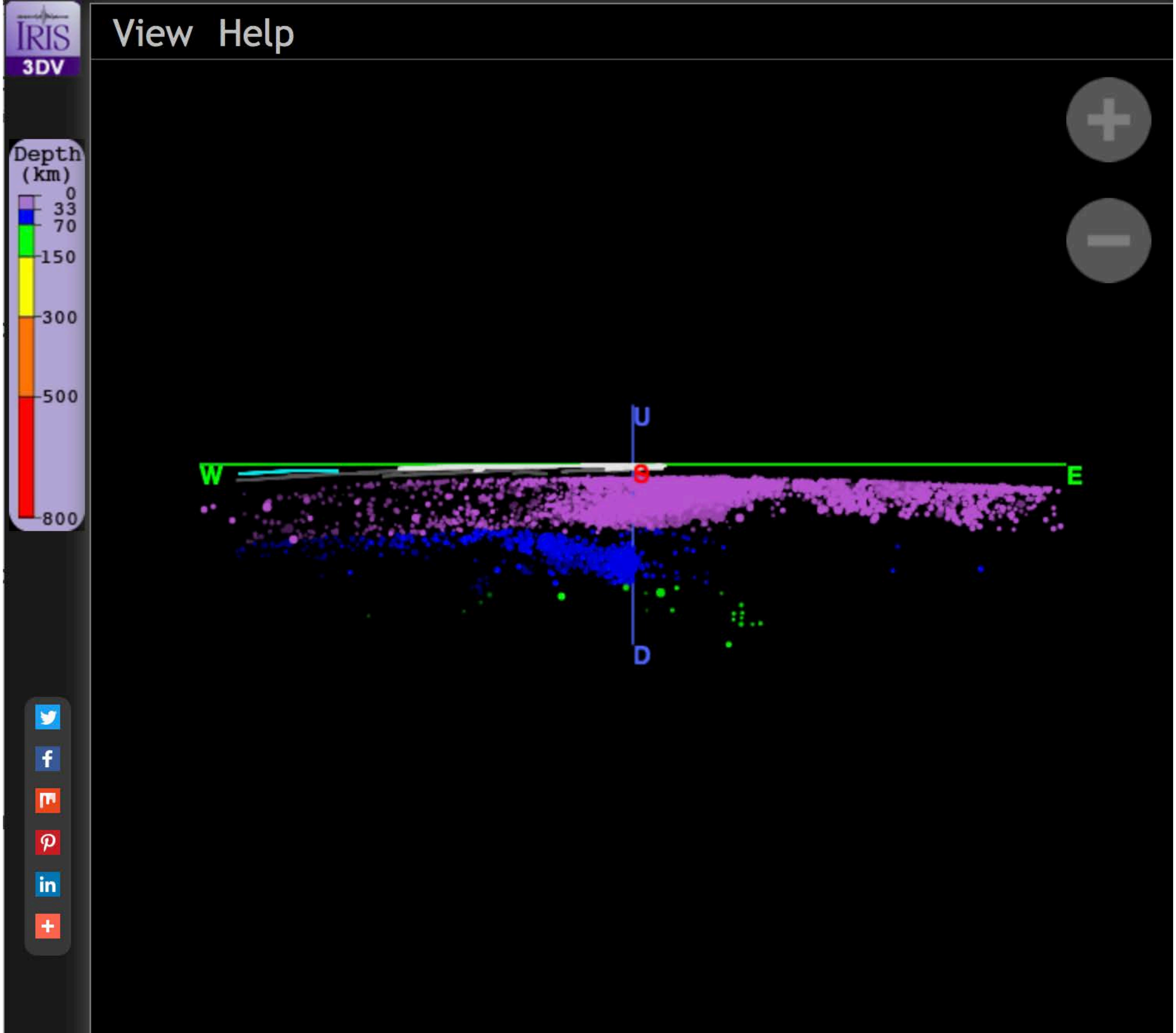
IRIS
3DV
View
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Depth
(km)
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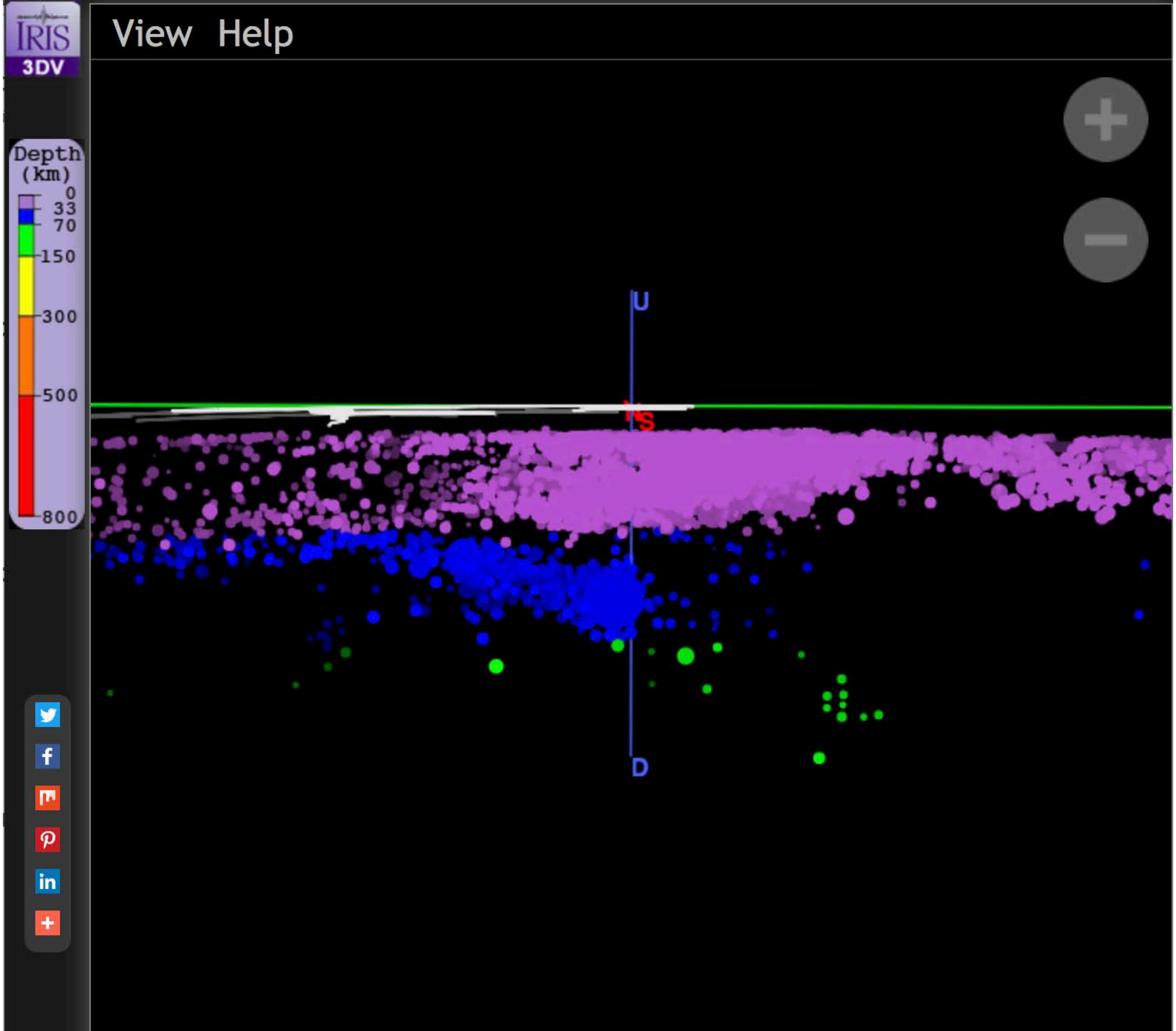
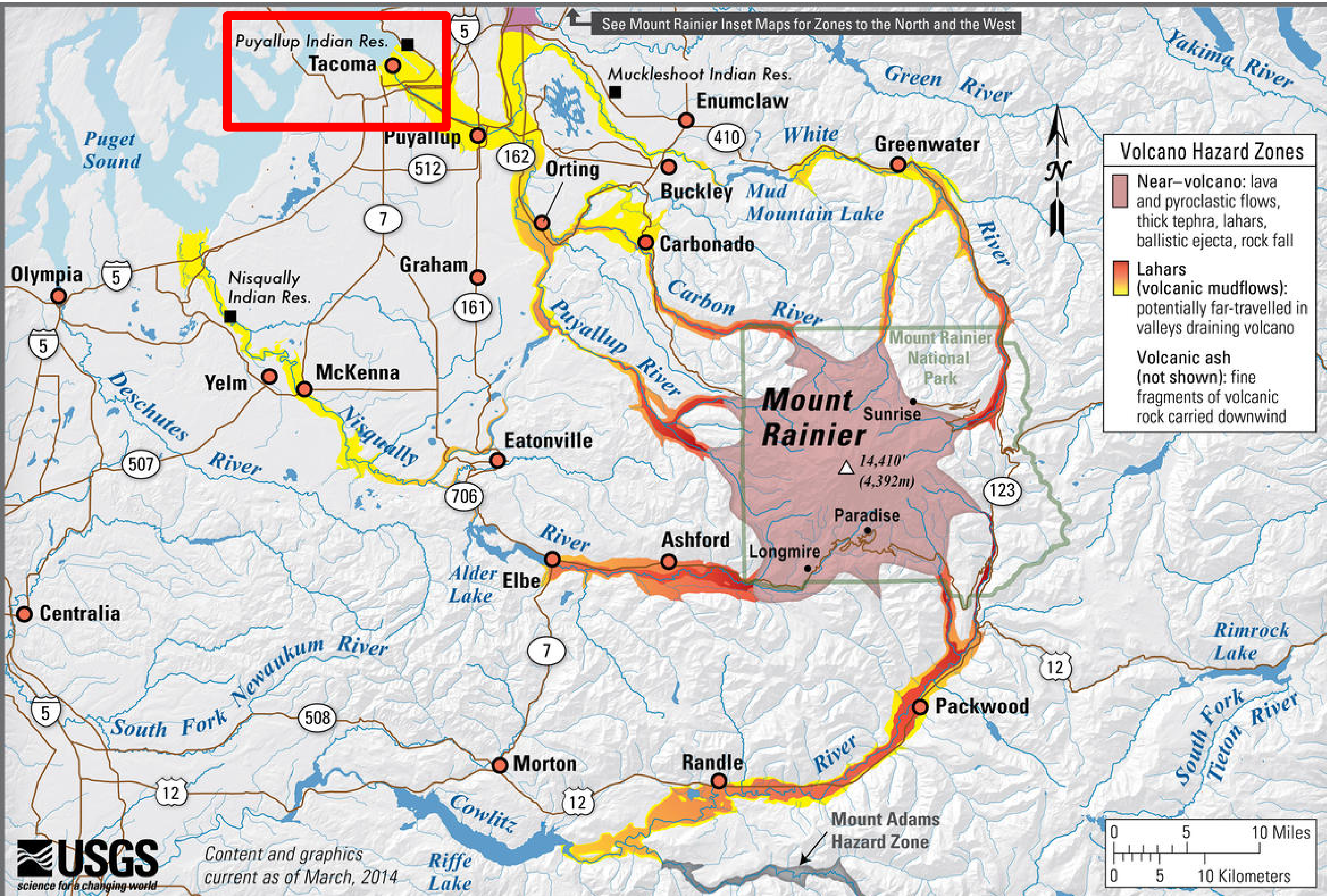
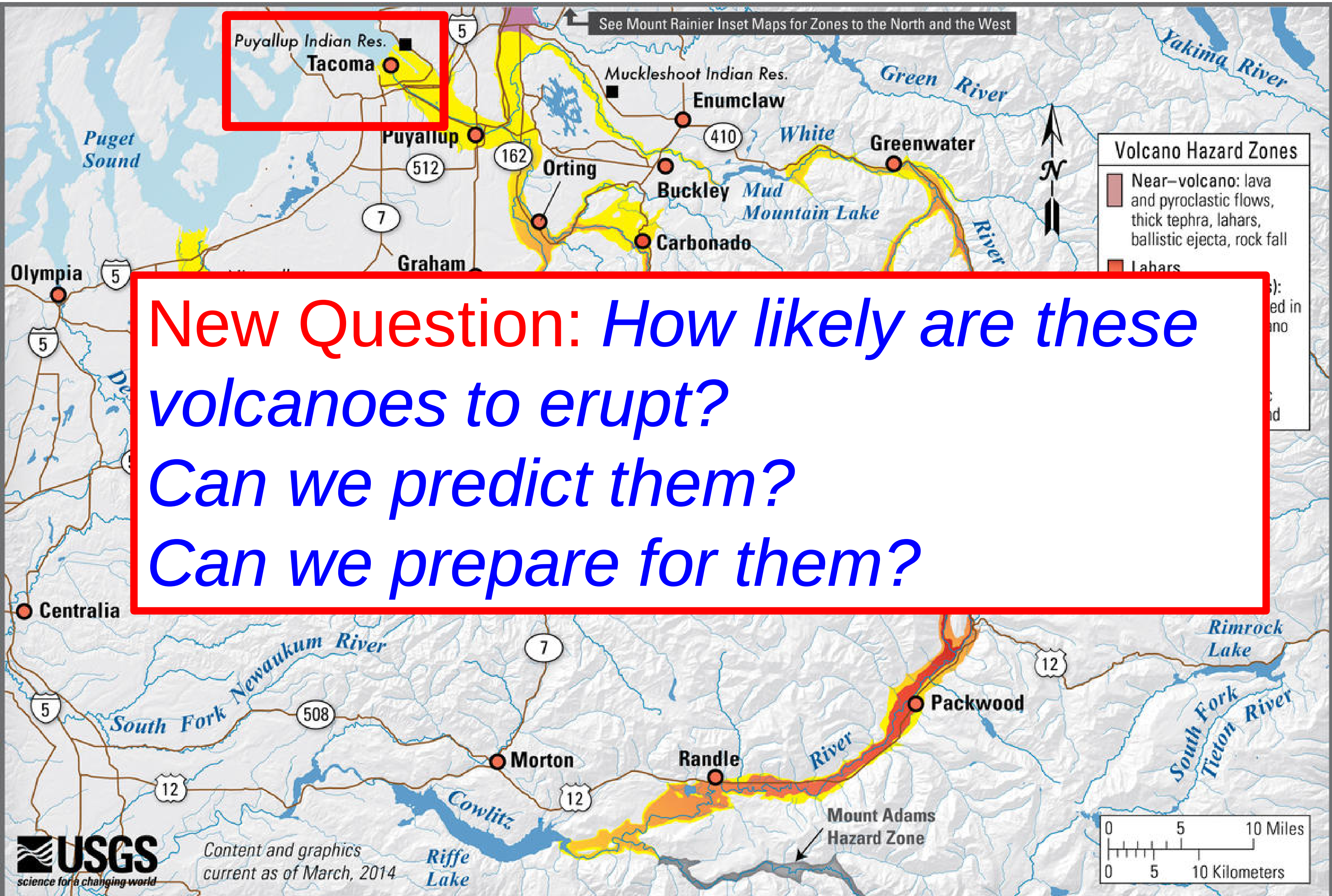

IRIS
3DV
View
Help
Depth
(km)
0
33
70
150
300
500
800
U
S
D

New Question: *What happens to Seattle and Tacoma when Mt. Rainier erupts?*

Mudflows from past volcanic eruptions



Mudflows from past volcanic eruptions

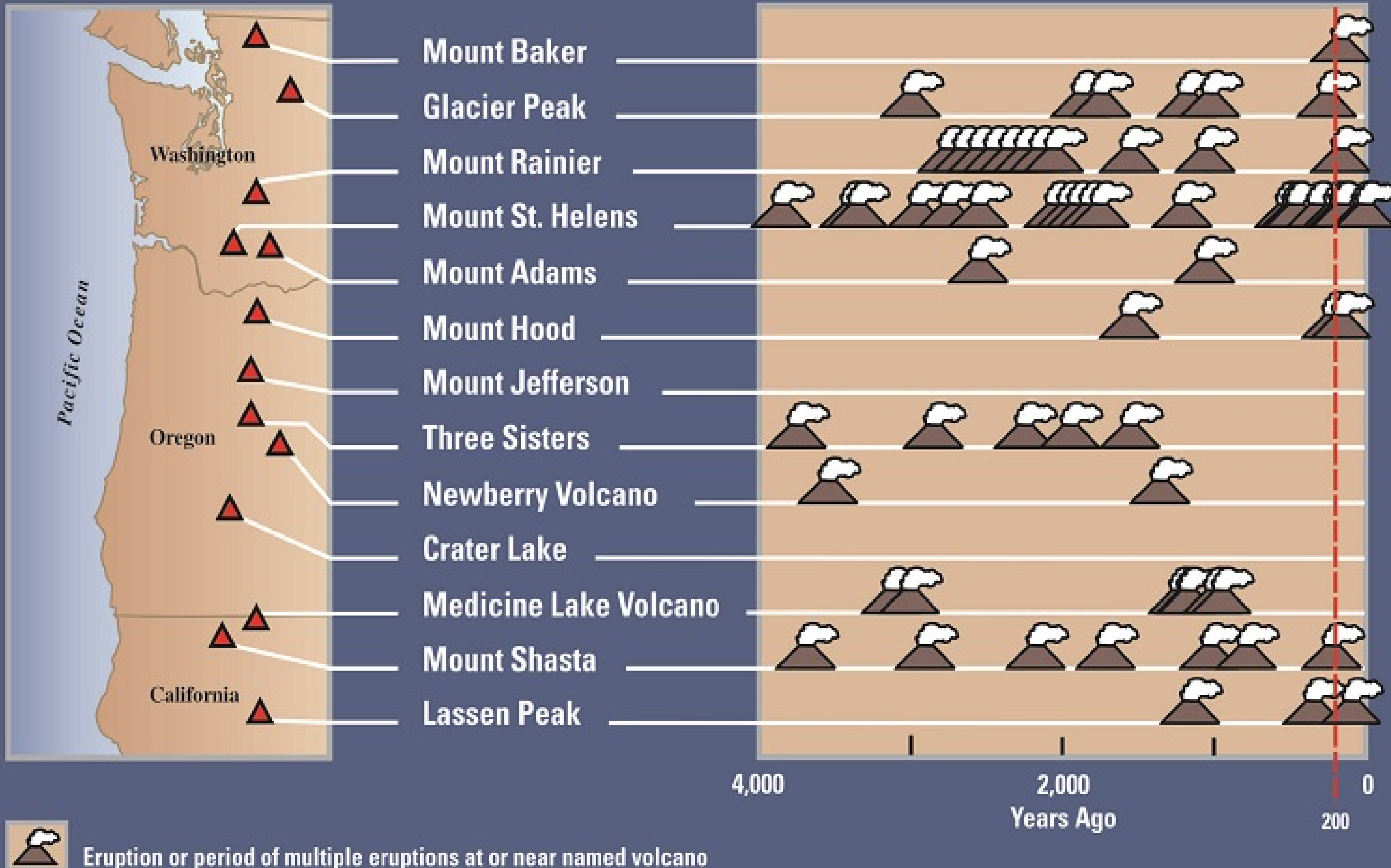


New Question: *How likely are these volcanoes to erupt?*

Can we predict them?

Can we prepare for them?

Eruptions in the Cascade Range During the Past 4,000 Years



NGSS: → Phenomenon-Based Learning

- Essential Questions start the process of generating ***STORYLINES***

NGSS Performance Expectations

MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

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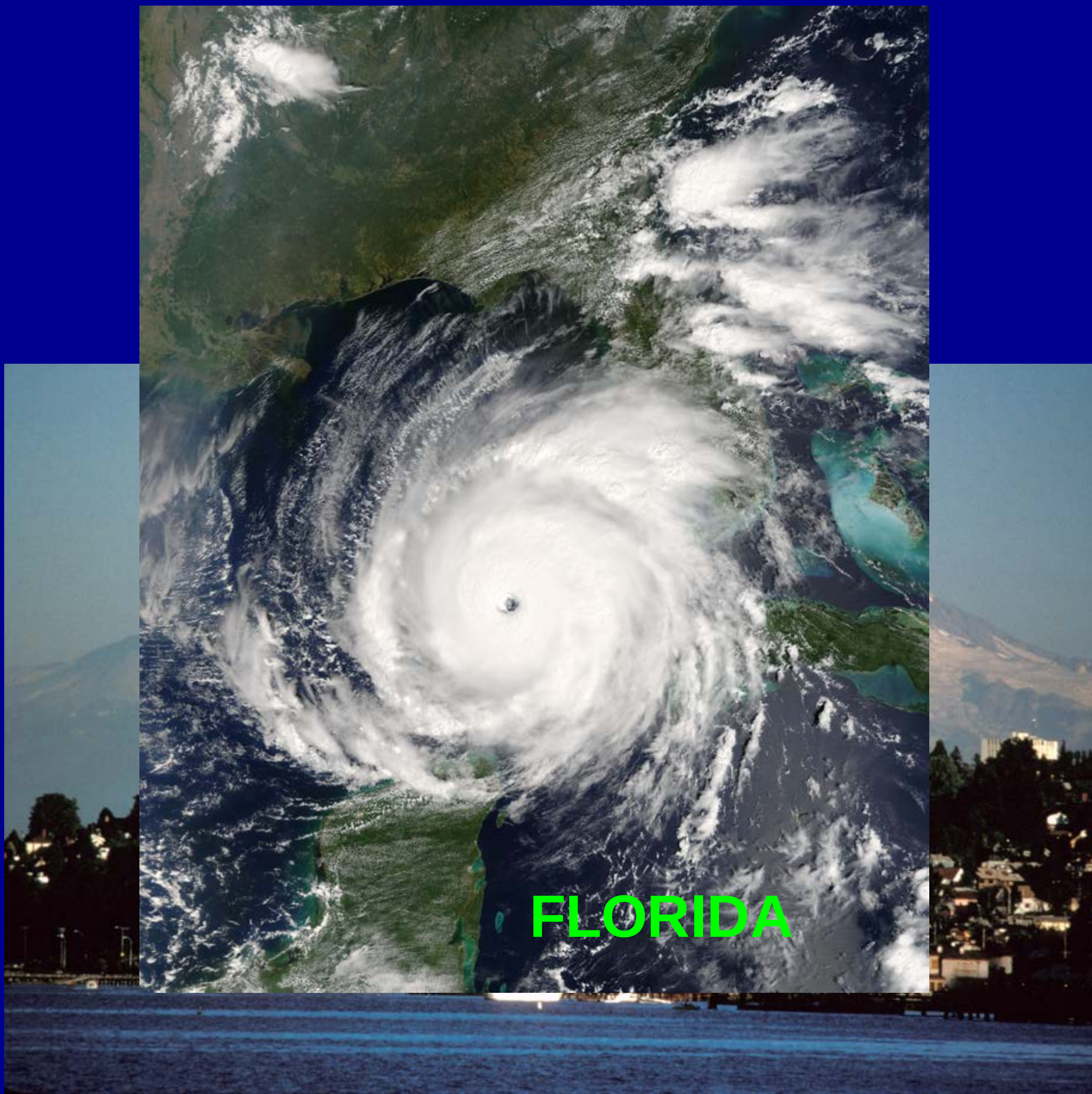
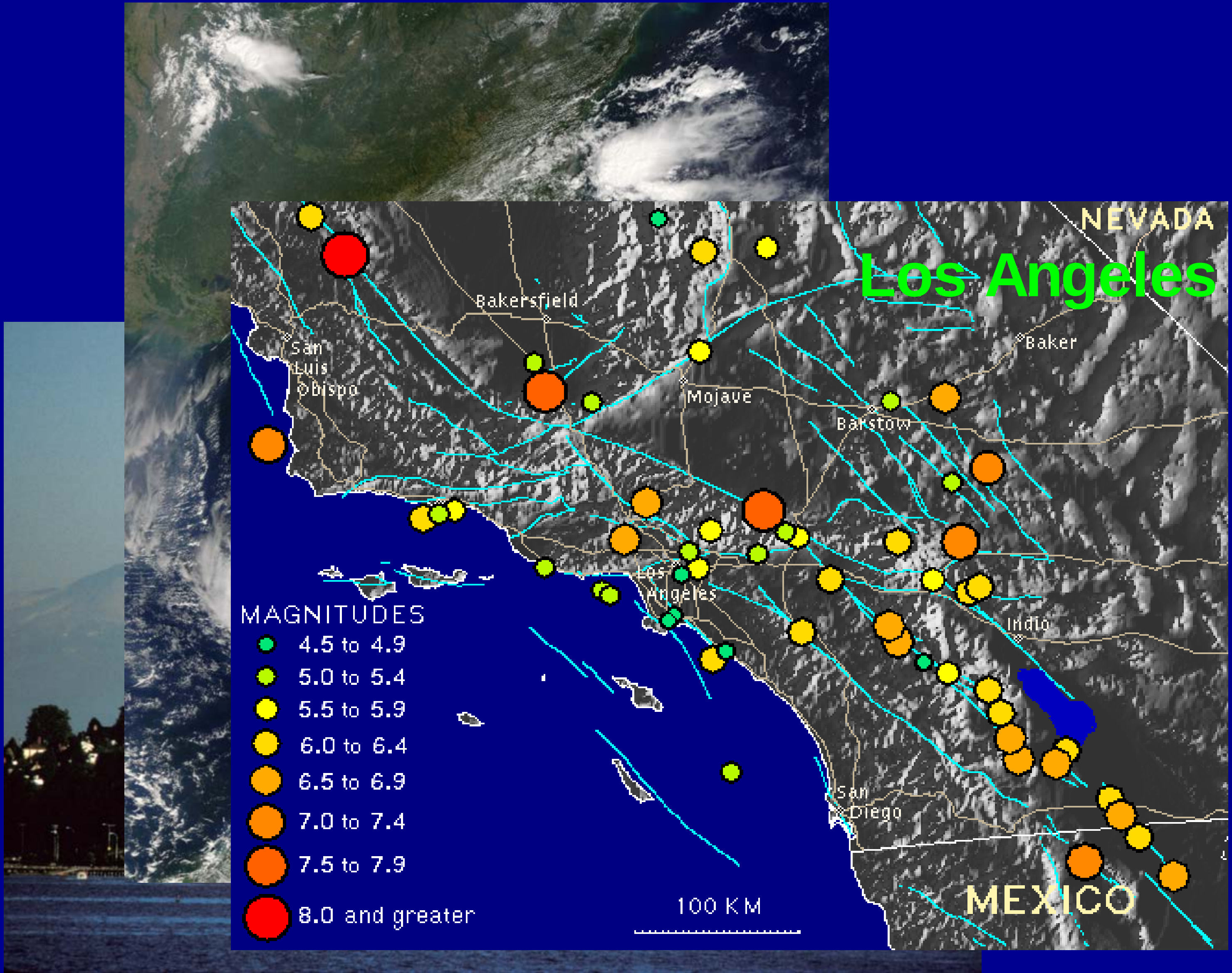


MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.



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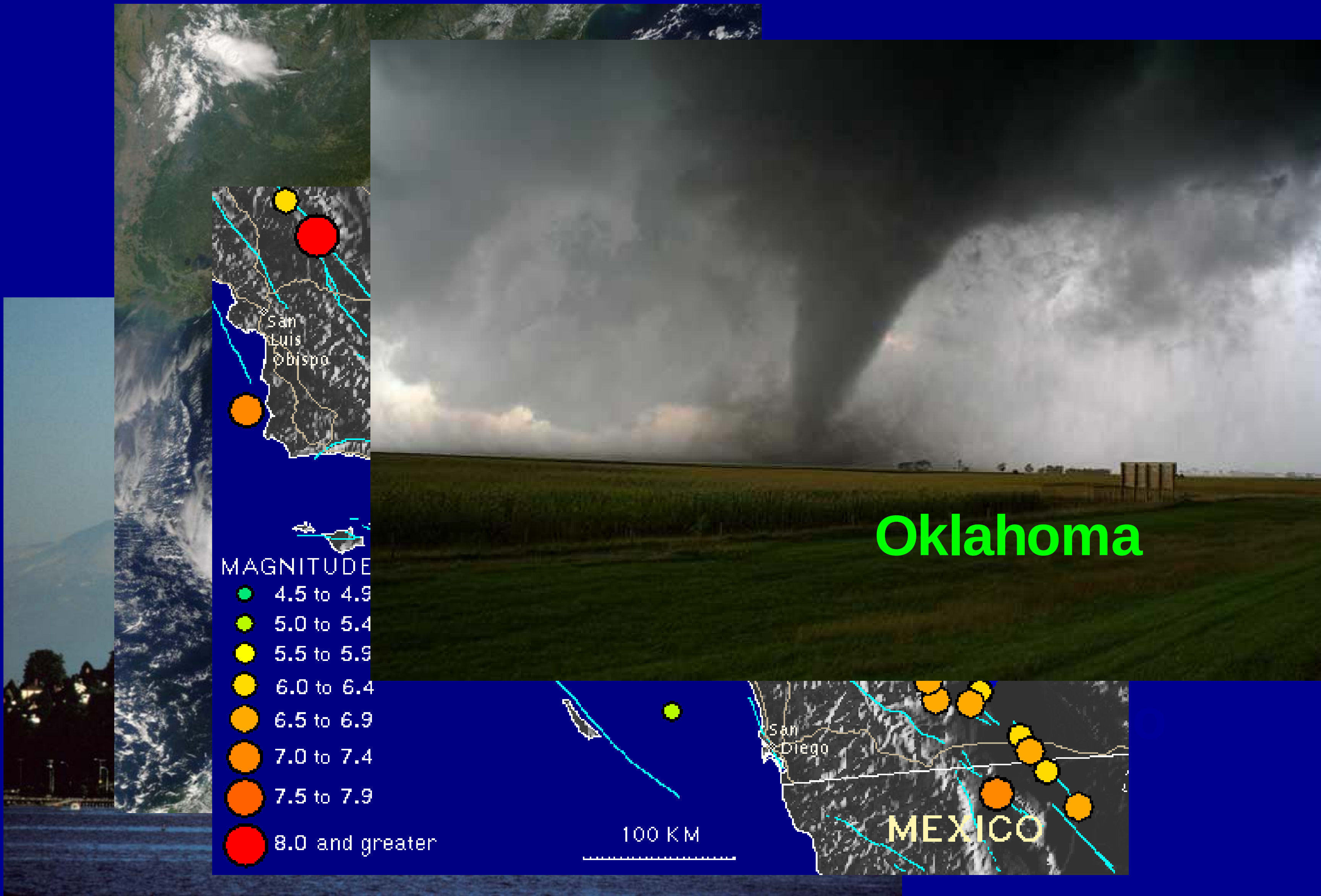

MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

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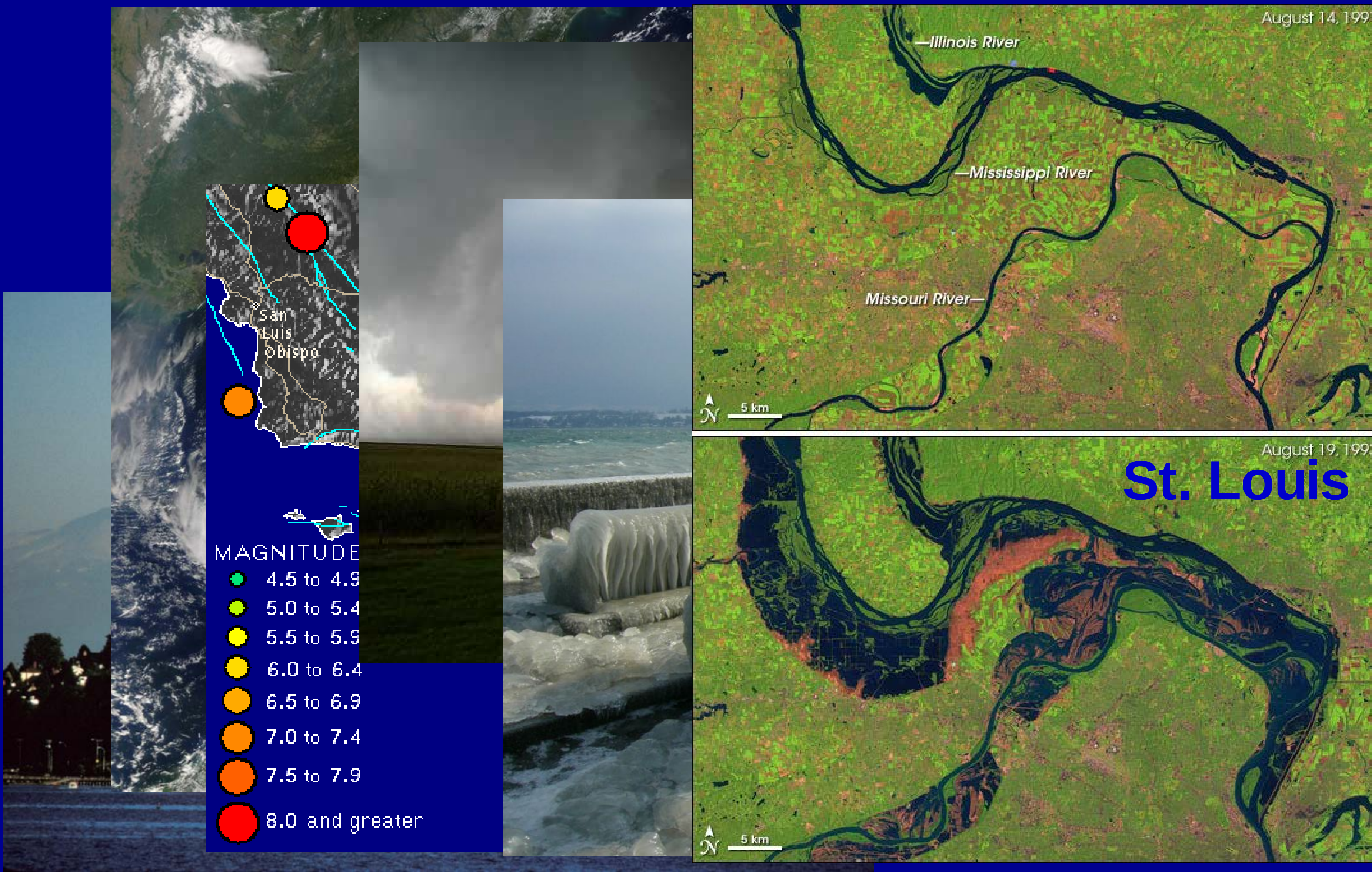

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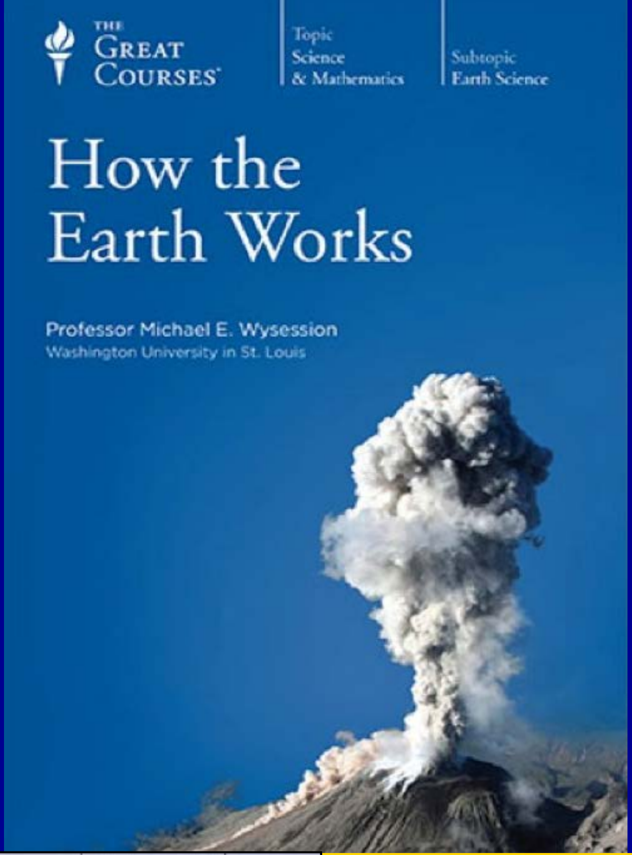
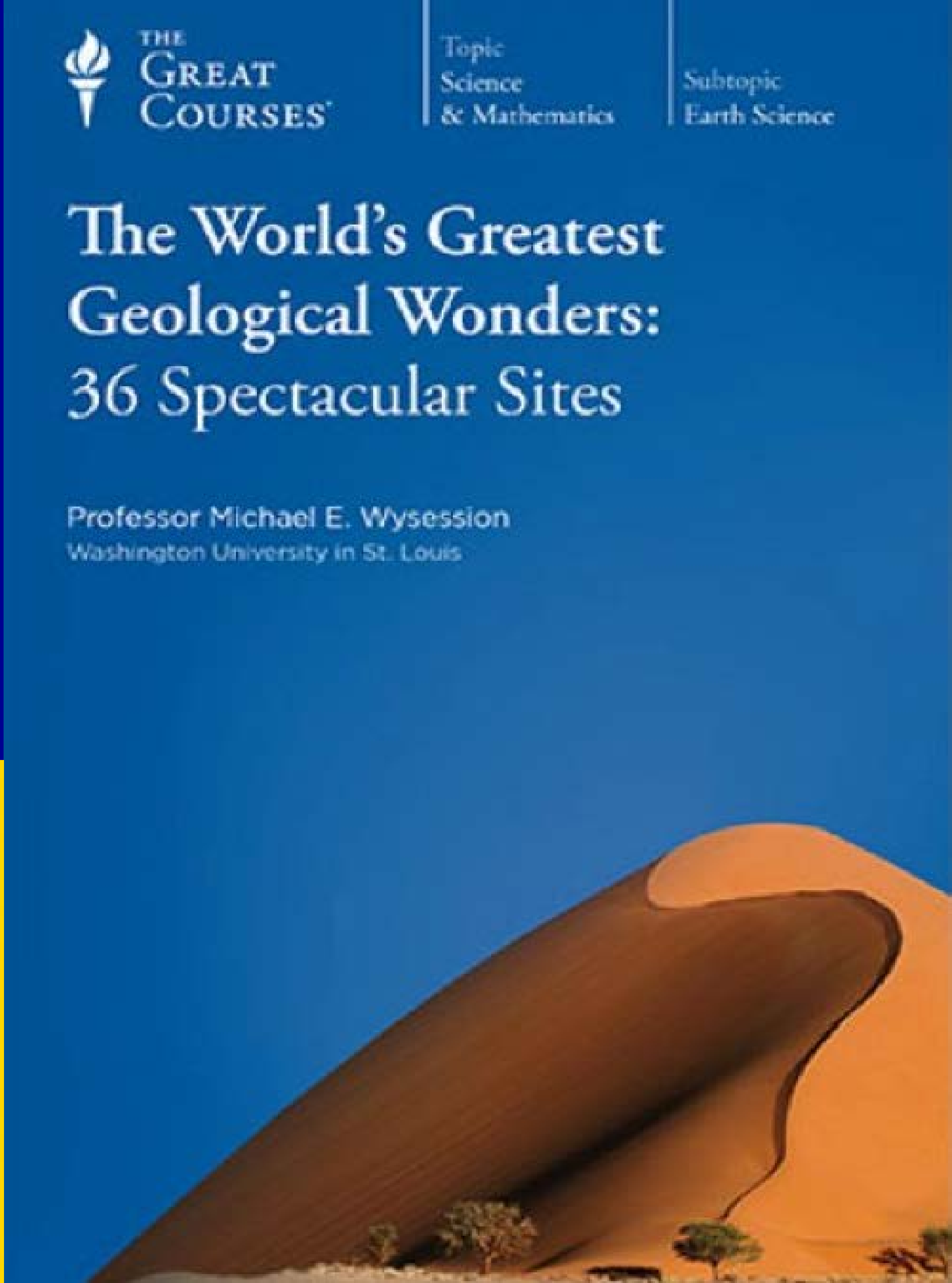
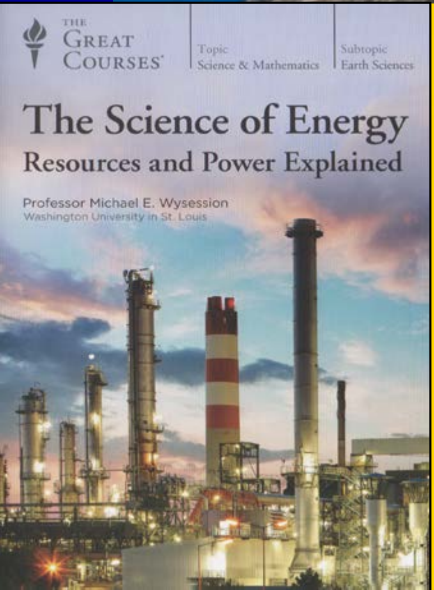
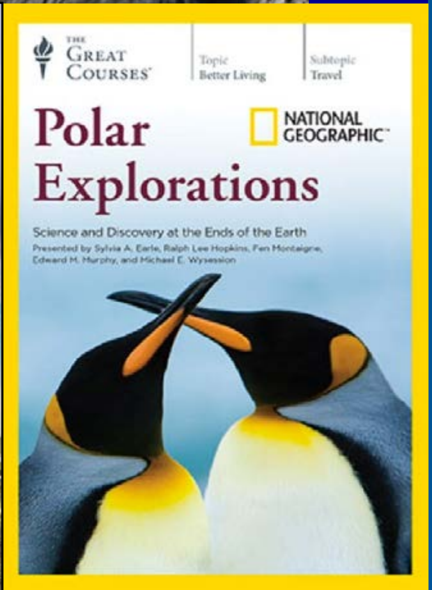
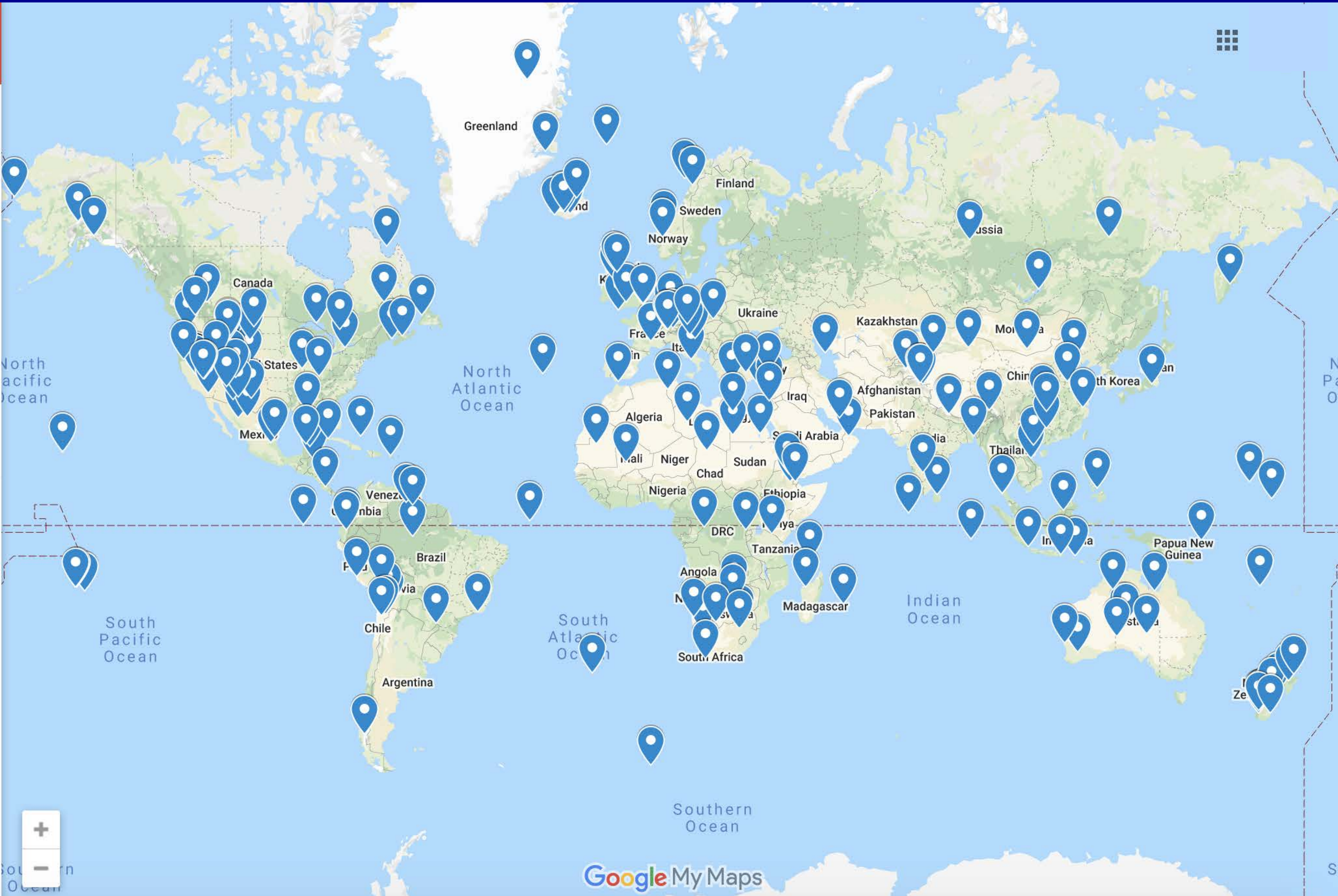

THE GREAT COURSES
Topic Science & Mathematics
Subtopic Earth Science
How the Earth Works
Professor Michael E. Wysession
Washington University in St. Louis


THE GREAT COURSES
Topic Science & Mathematics
Subtopic Earth Science
The World's Greatest Geological Wonders: 36 Spectacular Sites
Professor Michael E. Wysession
Washington University in St. Louis


THE GREAT COURSES
Topic Science & Mathematics
Subtopic Earth Sciences
The Science of Energy
Resources and Power Explained
Professor Michael E. Wysession
Washington University in St. Louis

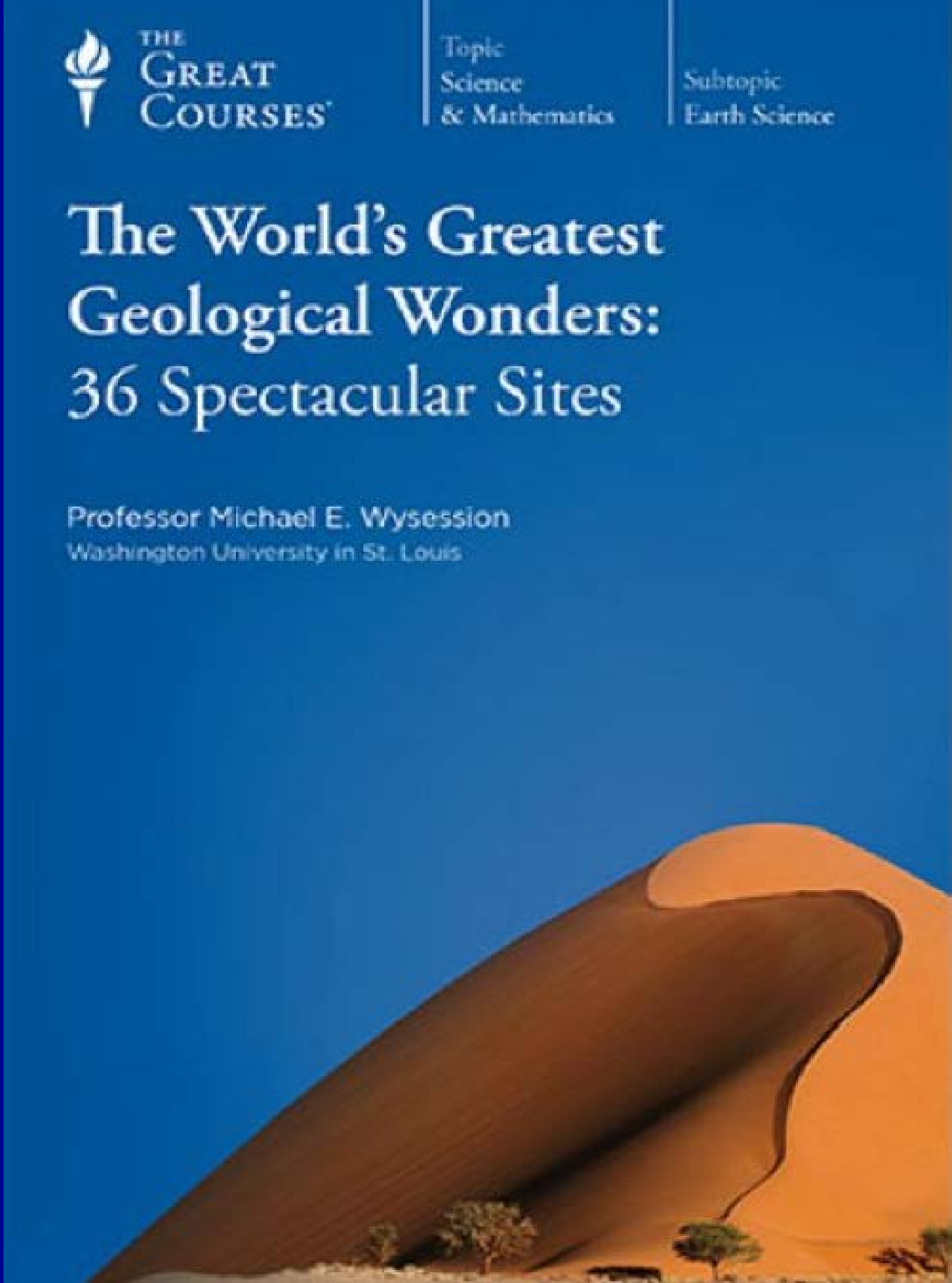

THE GREAT COURSES
Topic Better Living
Subtopic Travel
Polar Explorations
NATIONAL GEOGRAPHIC
Science and Discovery at the Ends of the Earth
Presented by Sylvia A. Earle, Ralph Lee Hopkins, Fen Montaigne, Edward M. Murphy, and Michael E. Wysession

Geologic Sites Discussed in the ***Geologic Wonders*** Video Course



Geoheritage Sites are wonderful for storylines for geoscience courses at all levels

Ex: **Earth and the Environment** (*EPS-201*), Washington University



CRYSTAL - A mineral grain displaying the characteristics of its atomic structure.

- Over 5000 different kinds of minerals (most due to life!) [5160 as of 9/15/16 - ~50 added each year]

- differences result from the different elements used and the ways they are bonded

Cave of Crystals

Cave of Crystals: Naica (Mexico)

Cave of Crystals:

Naica Mine

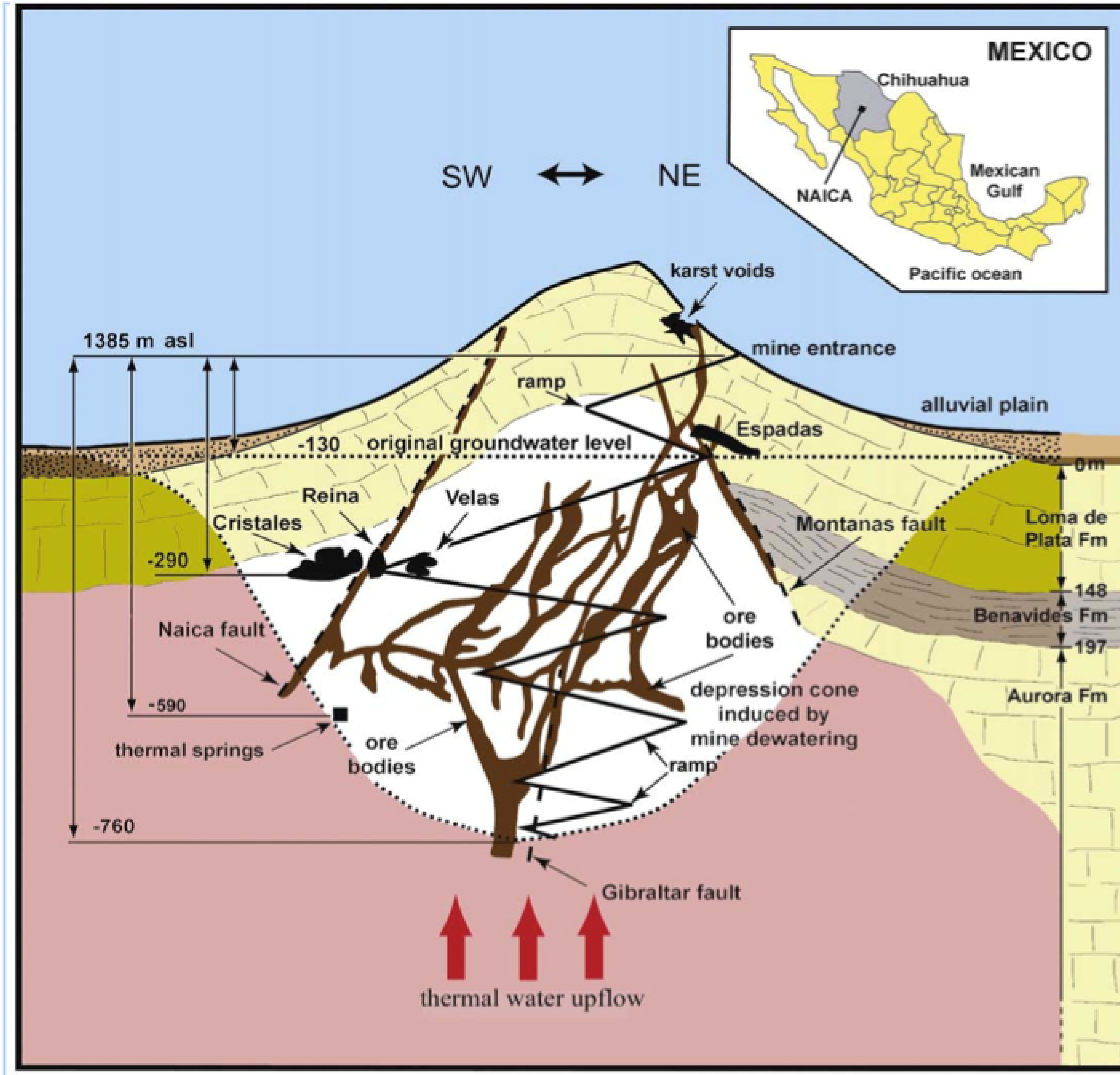
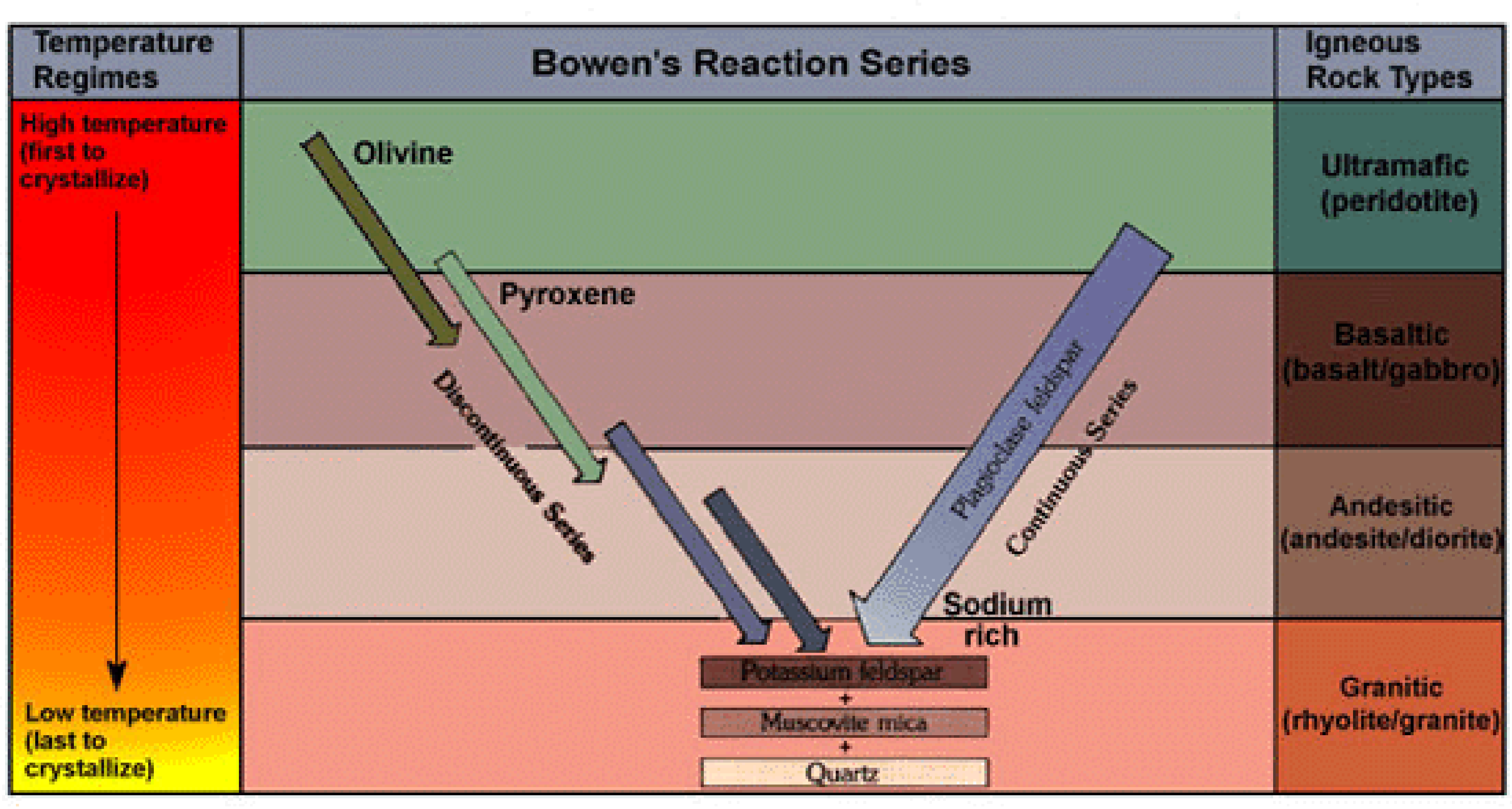


Fig. 1: An illustration detailing the stratigraphy of the area around the Naica Mine and the locations of the caves that have been found in the mine, including Cueva de las Espadas (Cave of Swords), Cueva de las Velas (Cave of Candles), Ojo de la Reina (Queen's Eye Cave), and Cueva de los Cristales (Cave of Crystals). The original level of the groundwater before pumping and the cone of depression resulting from the pumping are also shown (Sabagun & Winchell, 2001).

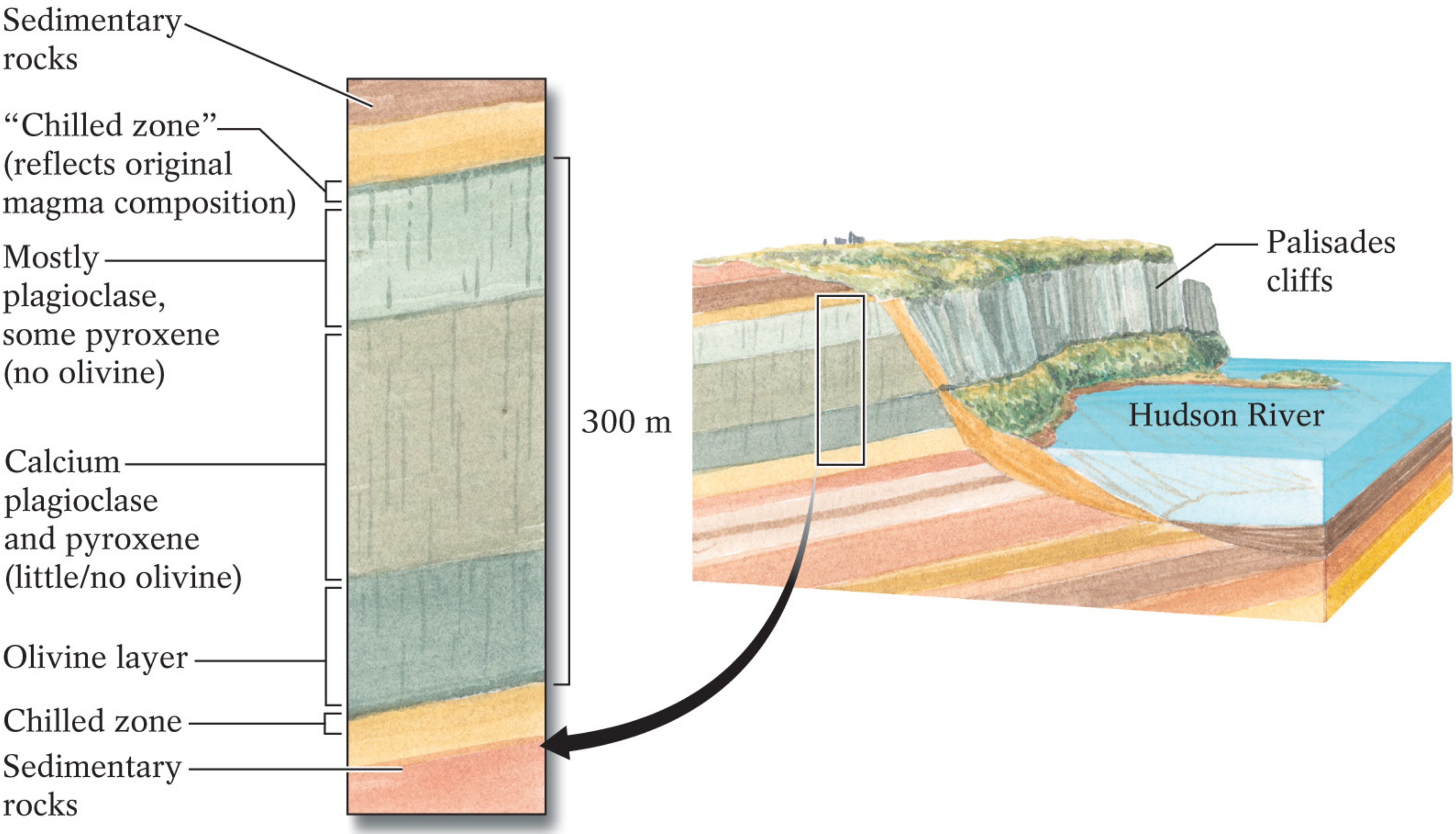
The last minerals to crystallize are quartz, sodium- and potassium-rich feldspars, and amphibole → granite!



(Therefore *ALSO* the first to melt!)

What happens if you start with molten rock and cool it?

Palisades Cliffs in New Jersey, along the Hudson River



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Volcanoes: Main Points

1) Magma forms inside Earth for several different reasons

2) These reasons are associated with the places that volcanoes occur

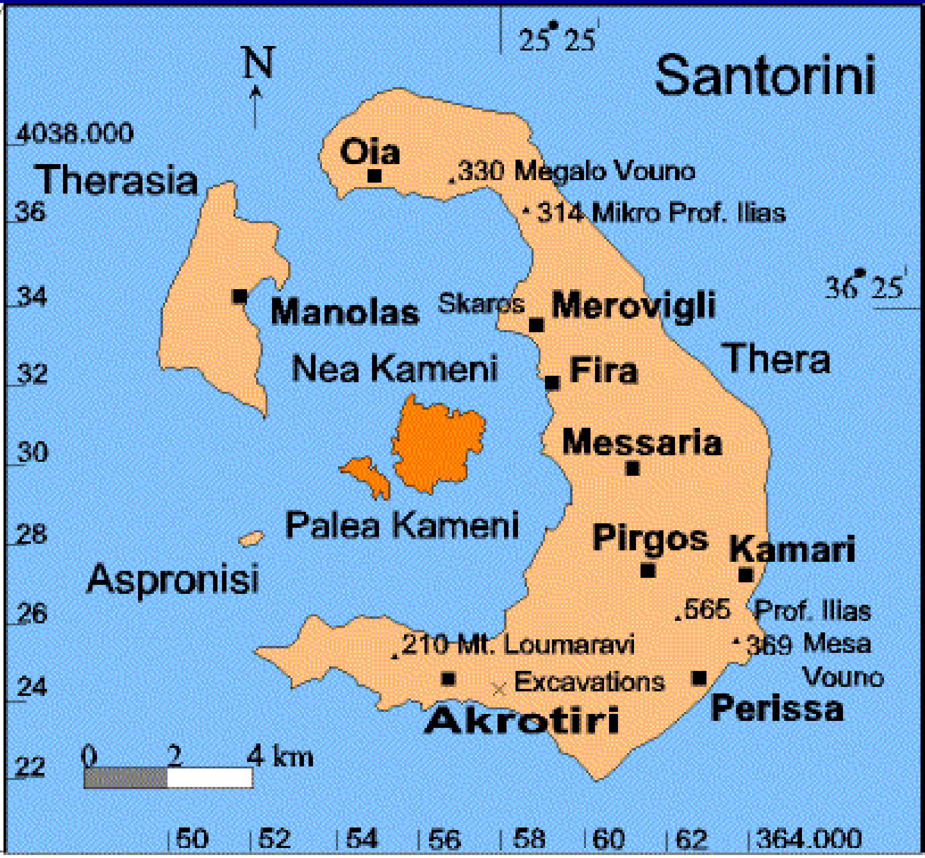
3) The viscosity of magma varies for several reasons

4) Volcanoes pose human hazards for several reasons

5) Supervolcanoes don’t happen very often (fortunately)


Dem Mittelmeer auf den Grund gesehen

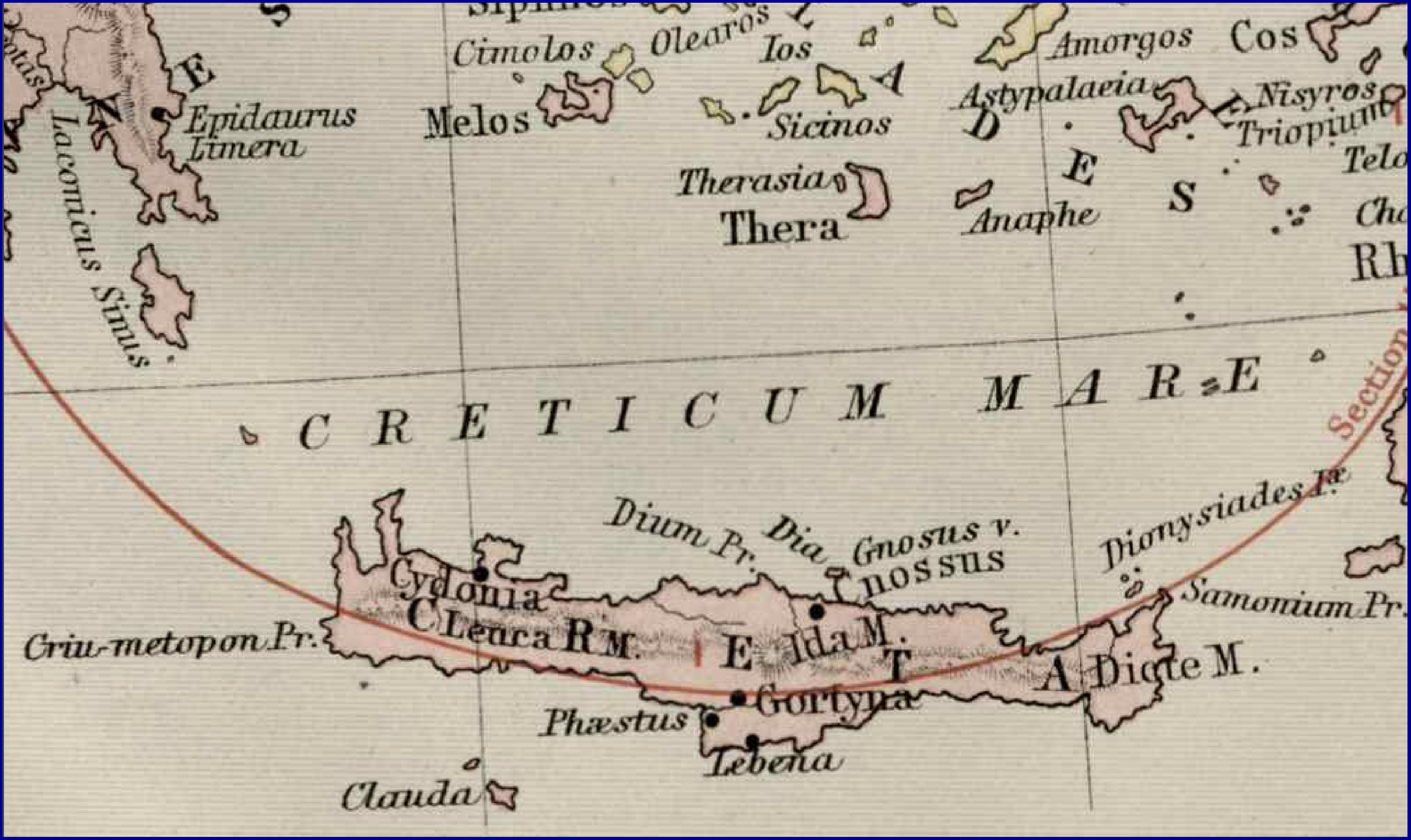
Map of Santorini (Thera)



Santorini: satellite view


ARIS

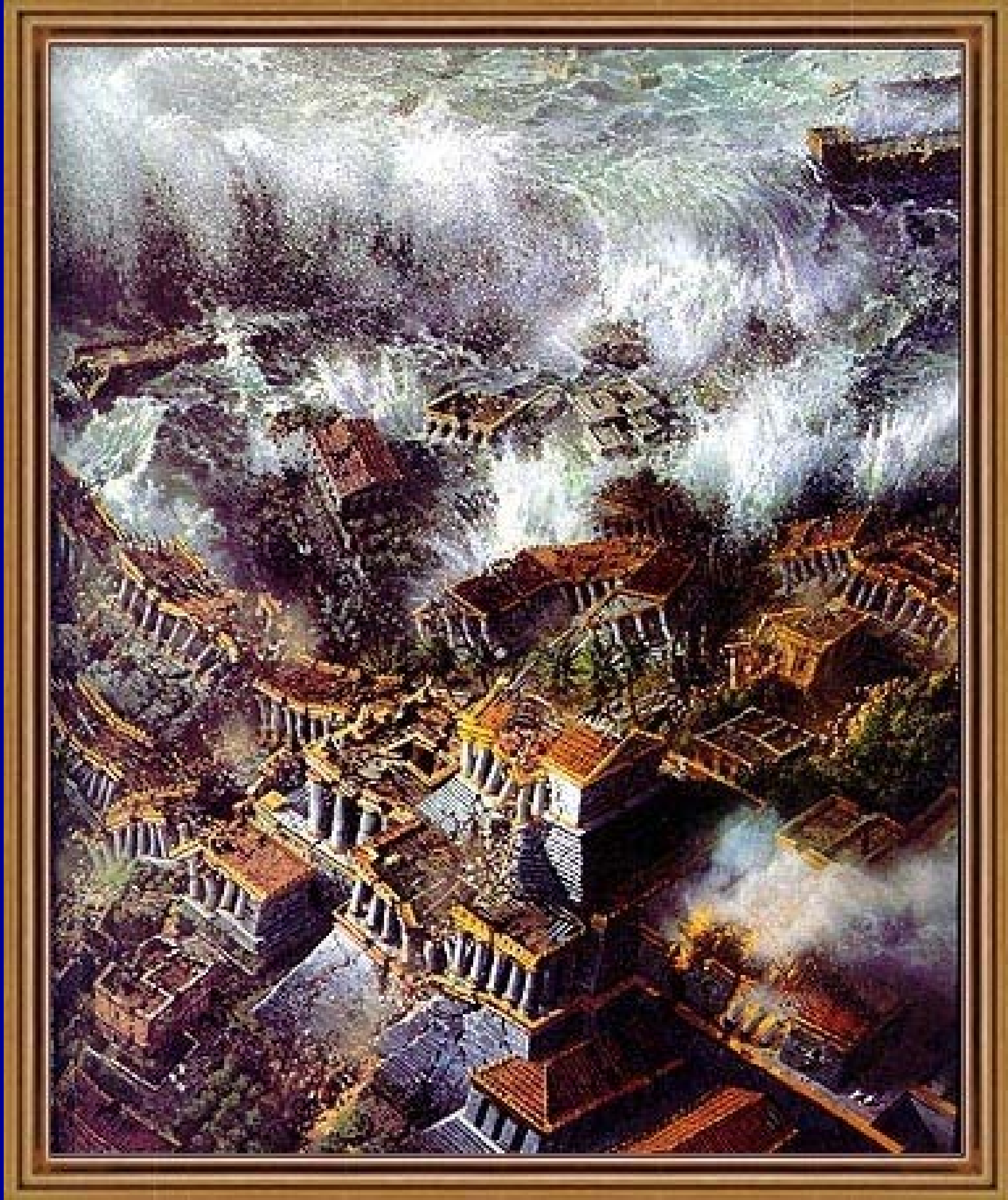

From the eruption of 1628 BCE



Crete and Santorini (Thera)

Archaeological excavation at Akrotiri

Picture of artist's idea of the sinking of Atlantis

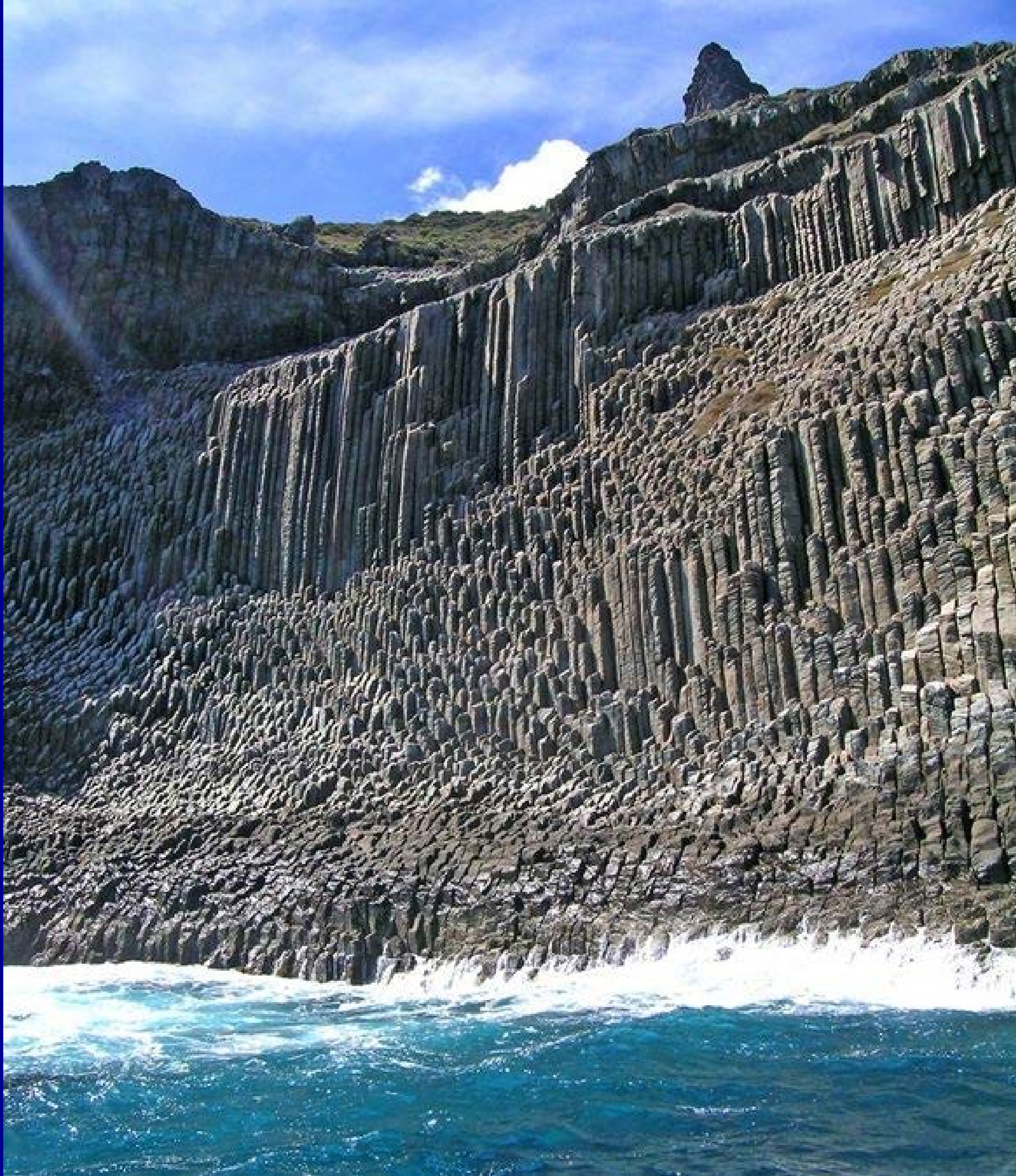


Devils Tower (Wyoming)

Devils Tower (Wyoming)

Giant's Causeway (Ireland)

Los Organos
(Canary Islands)

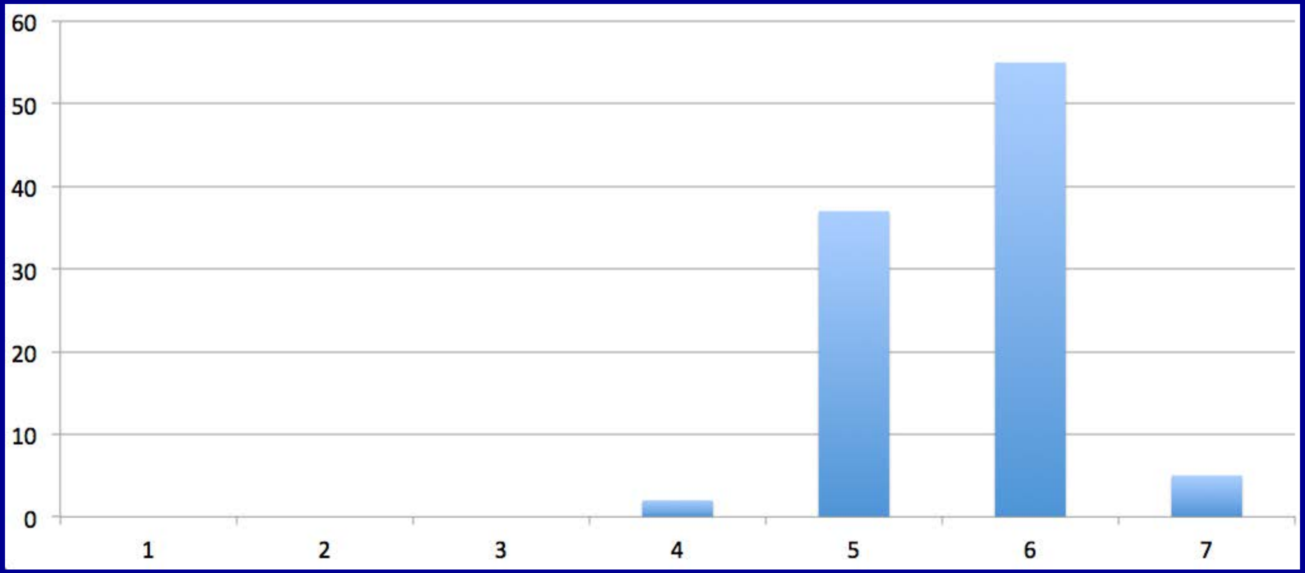


Devil's Postpile (California)

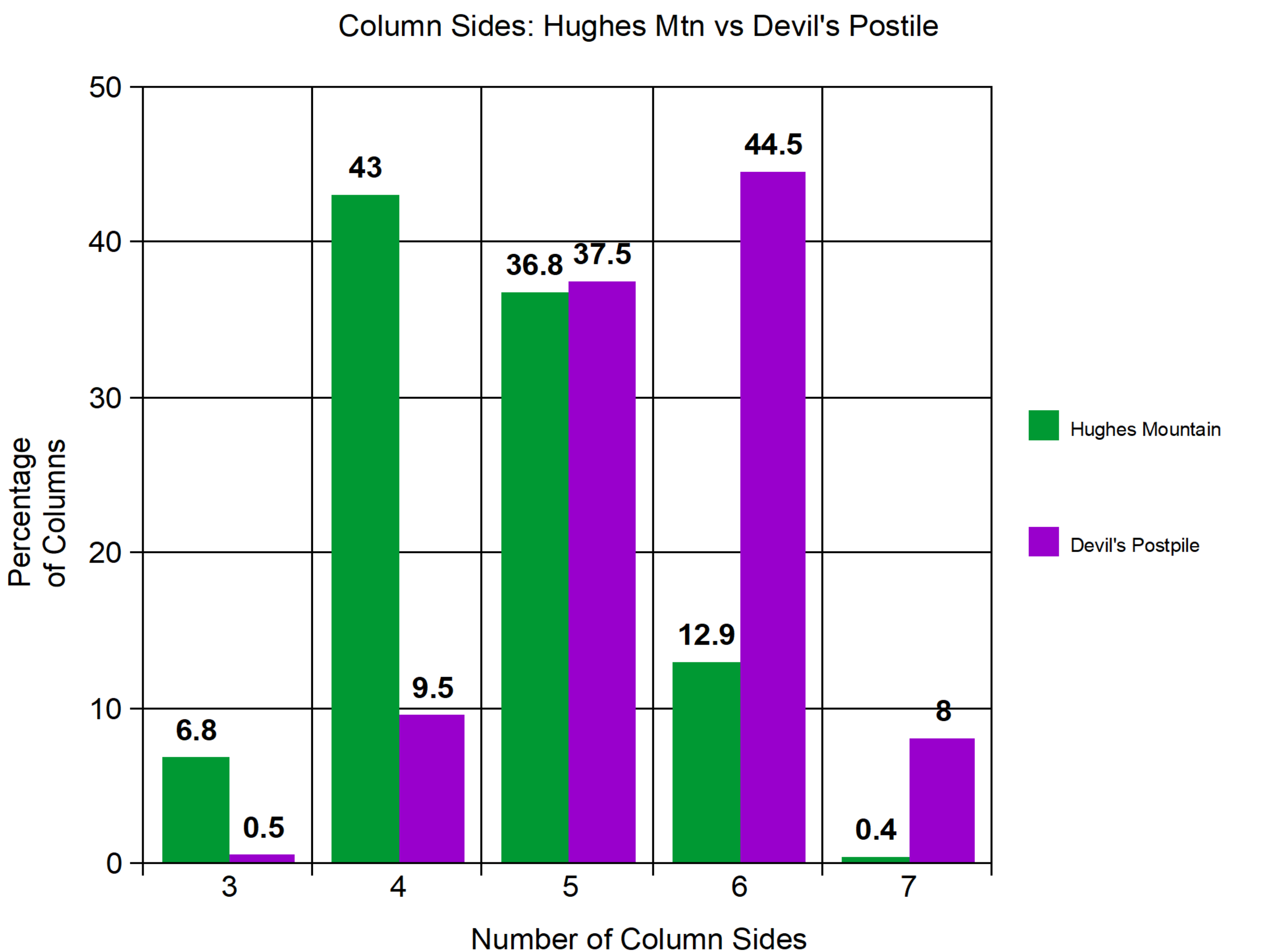
Devil's Postpile (CA)

- Basalt layer
- 400 ft deep lava lake; 3 miles long
- Columns: up to 3.5 ft wide, 18 ft long

3 sides – 0%
4 sides – 2%
5 sides – 37%
6 sides – 55%
7 sides – 5%




Hughes Mountain (MO)


Column Sides: Hughes Mtn vs Devil's Postile
Percentage of Columns
Number of Column Sides
0
10
20
30
40
50
3
4
5
6
7
6.8
0.5
43
9.5
36.8
37.5
12.9
44.5
0.4
8
Hughes Mountain
Devil's Postpile

Chemical Weathering:

1) Dissolution

2) Hydrolysis

3) Oxidation

→ More significant than *mechanical weathering* (in volume of rock affected)

→ Especially dominant in wet climates

Halong Bay, Vietnam

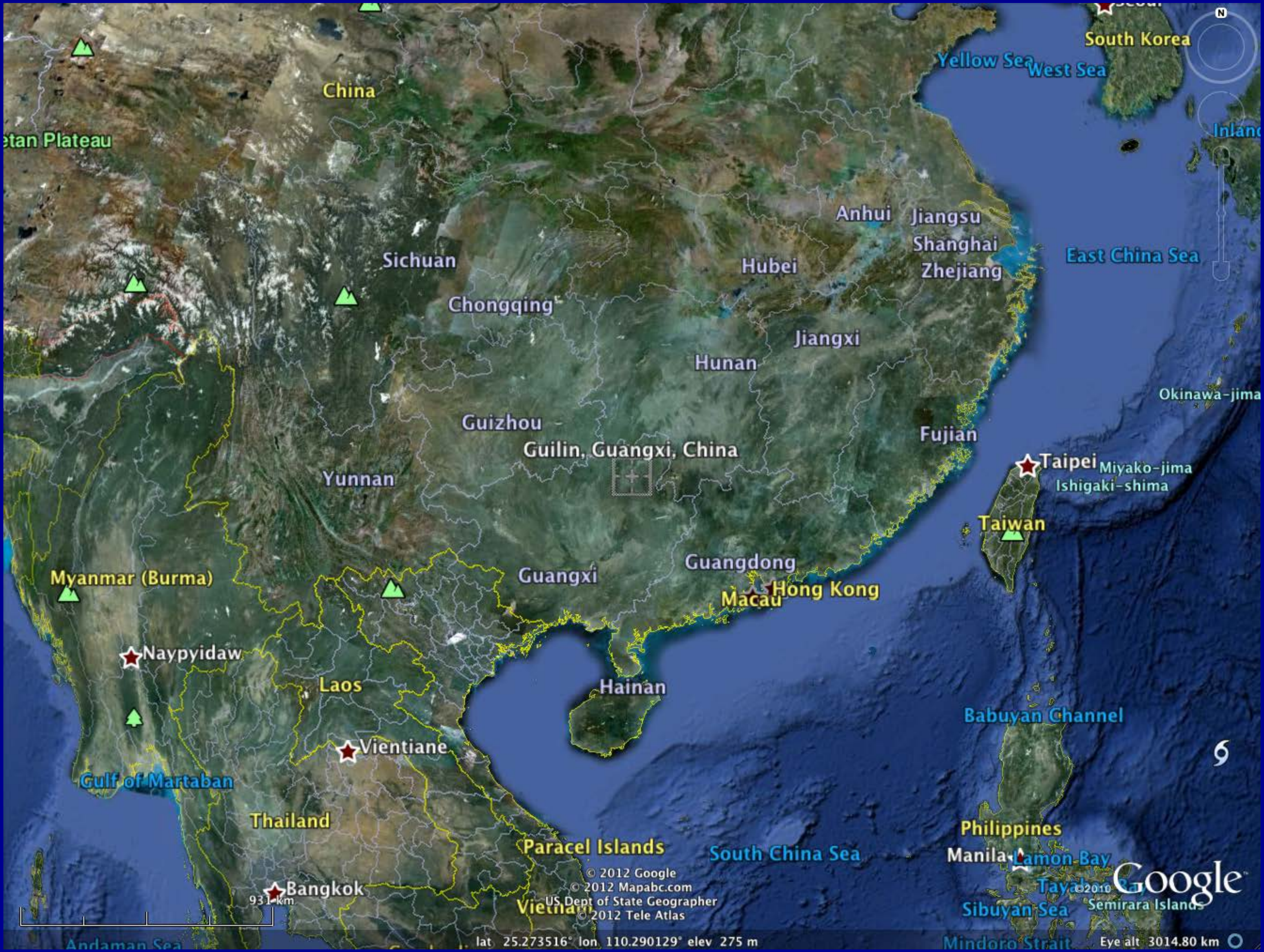
Halong Bay, Vietnam

Halong Bay: Karst Topography

Halong Bay

Halong Bay: Floating Villages

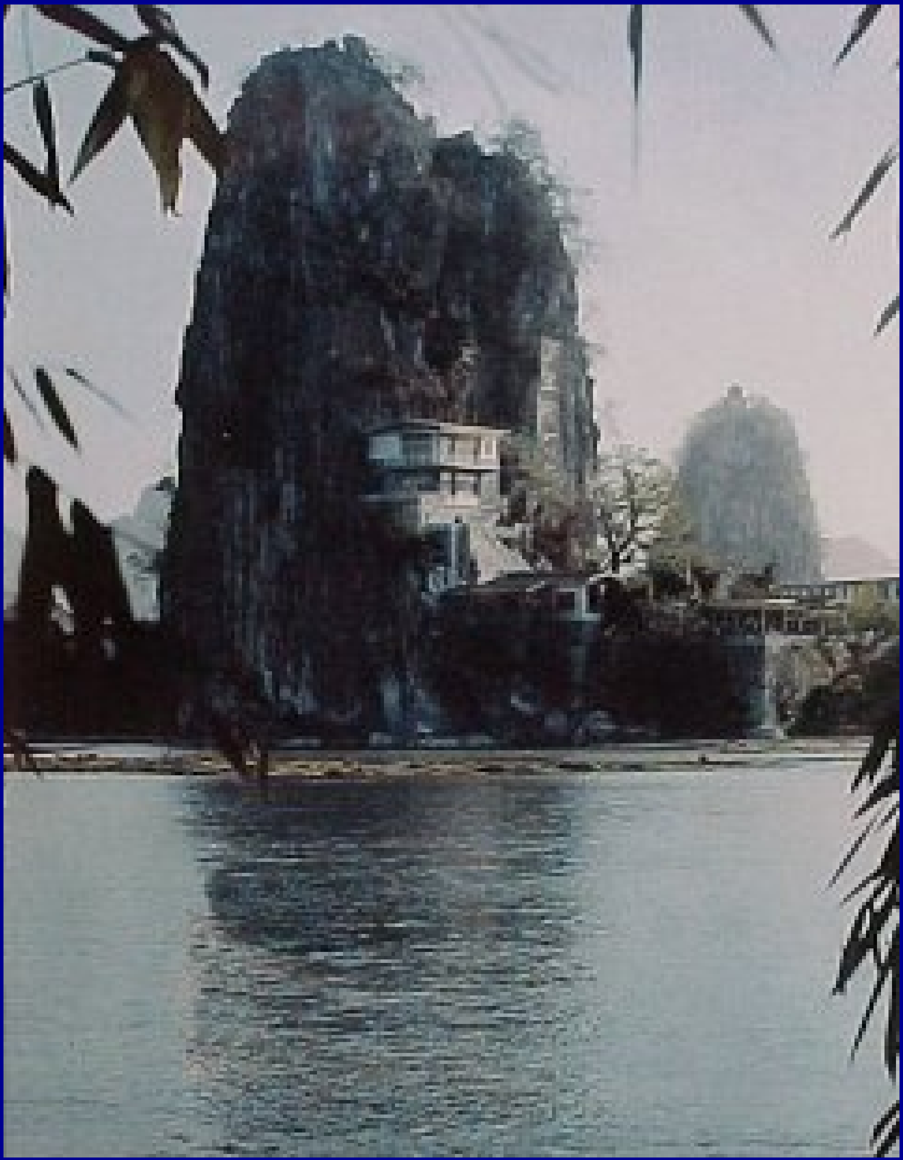
Guilin, China



Guilin

Guilin in Art

Guilin in Art



Phang Nga Bay, Thailand

Phang Nga Bay, Thailand

James Bond:

The Man with the Golden Gun

Phang Nga Bay, Thailand

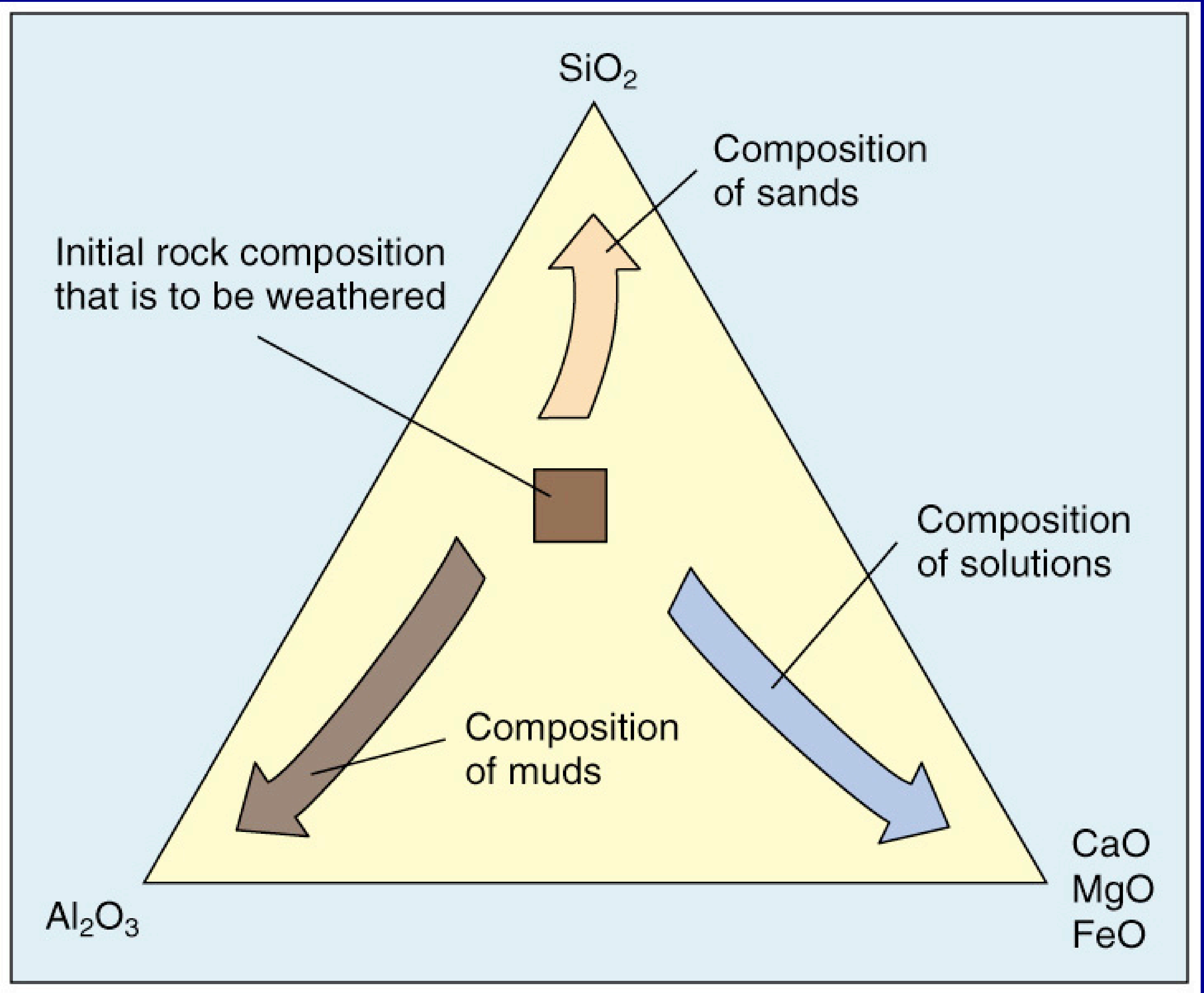
James Bond:

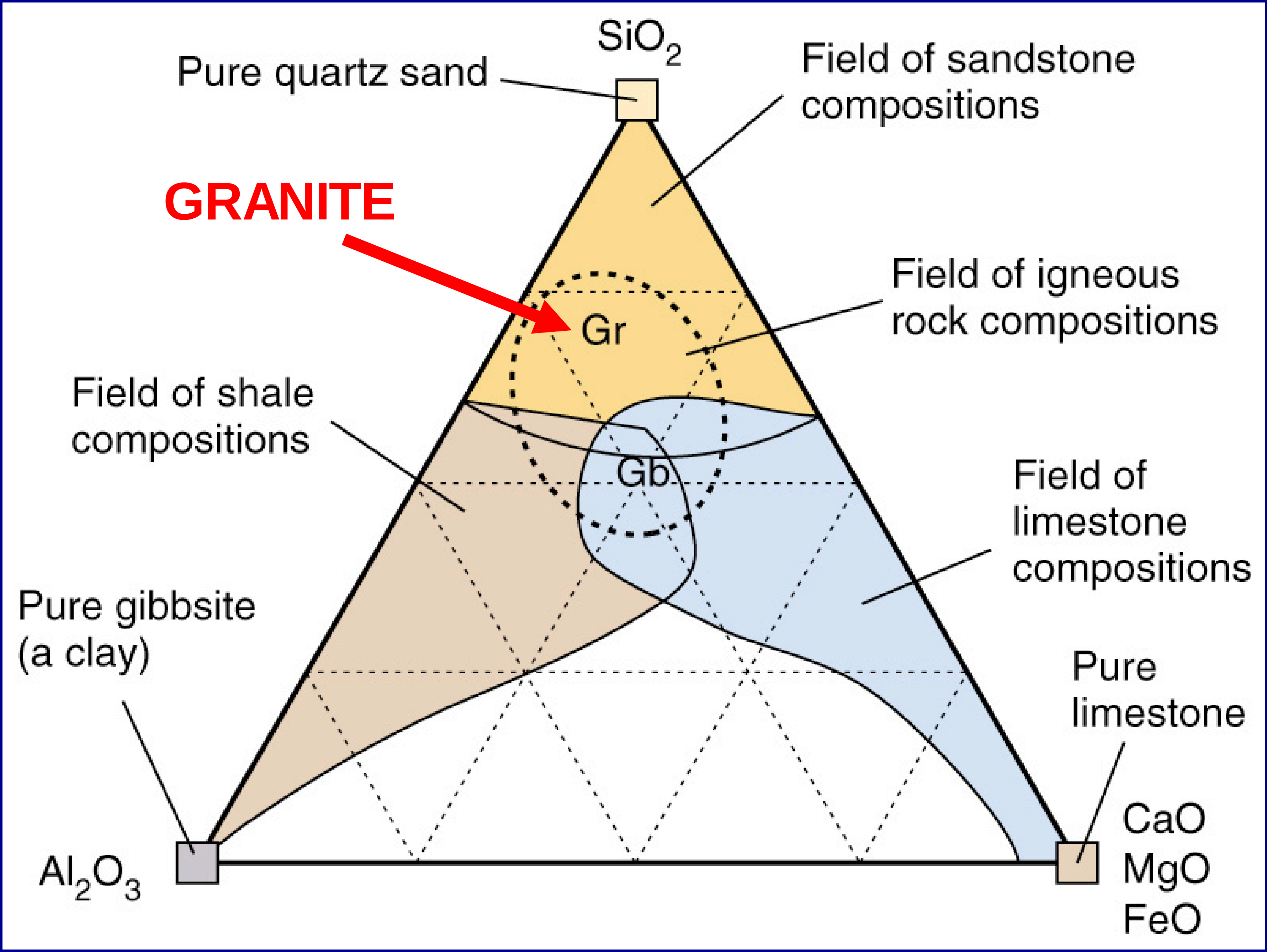
The Man with the Golden Gun

Elephant Rocks (Missouri)

Q? Where does all the granite go?

Q? Where does all the granite go?

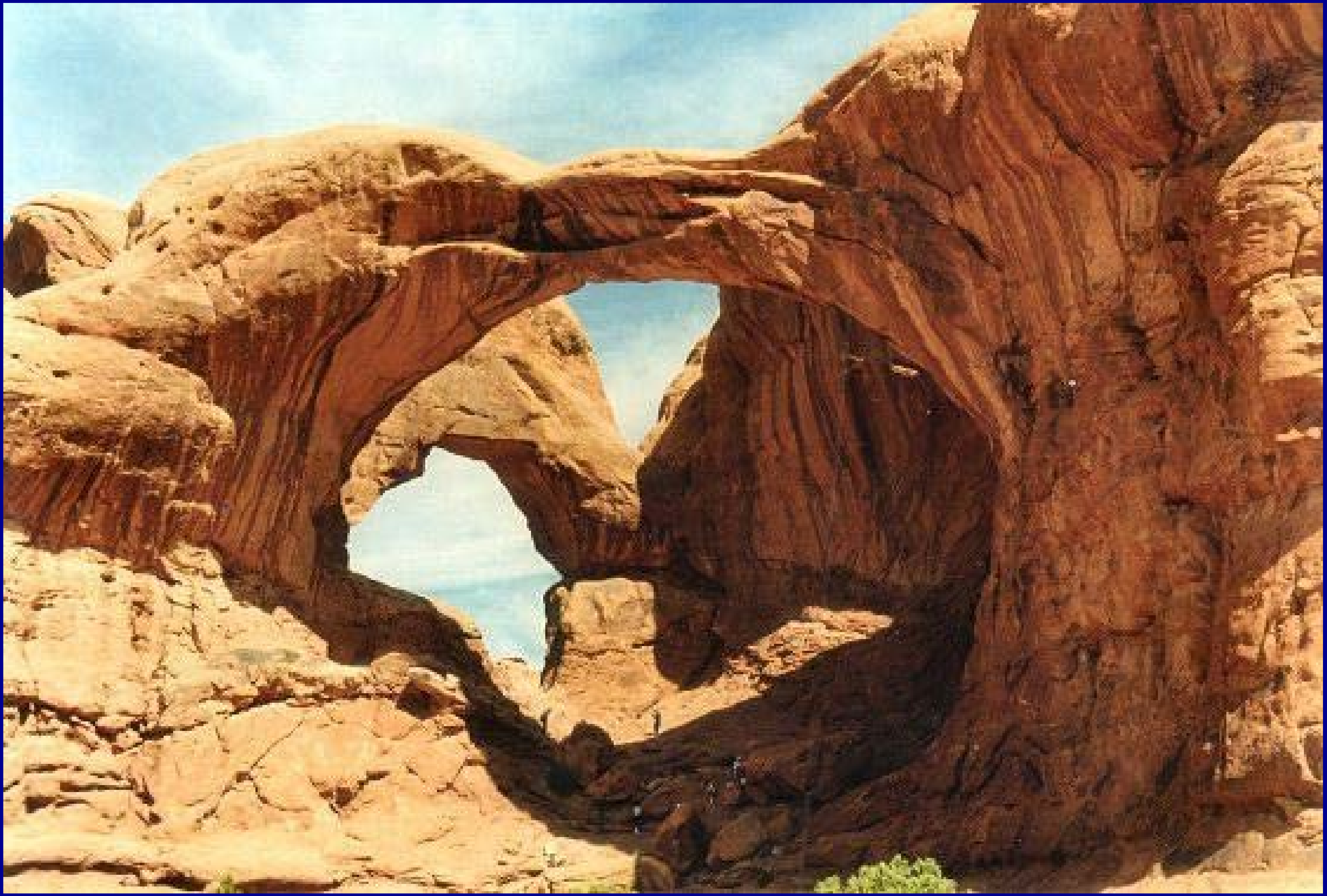

SiO_2
Composition of sands
Initial rock composition that is to be weathered
Composition of solutions
Composition of muds
Al_2O_3
CaO
MgO
FeO



SiO2
Pure quartz sand
Field of sandstone compositions
GRANITE
Gr
Field of igneous rock compositions
Field of shale compositions
Gb
Field of limestone compositions
Pure gibbsite (a clay)
Pure limestone
Al2O3
CaO
MgO
FeO

Bryce Canyon

Arches National Park, Utah



“The Wave:” Arizona

Bisti Badlands, NM

South Dakota Badlands

Chiricahua National Monument, Arizona

City of Rocks, Idaho