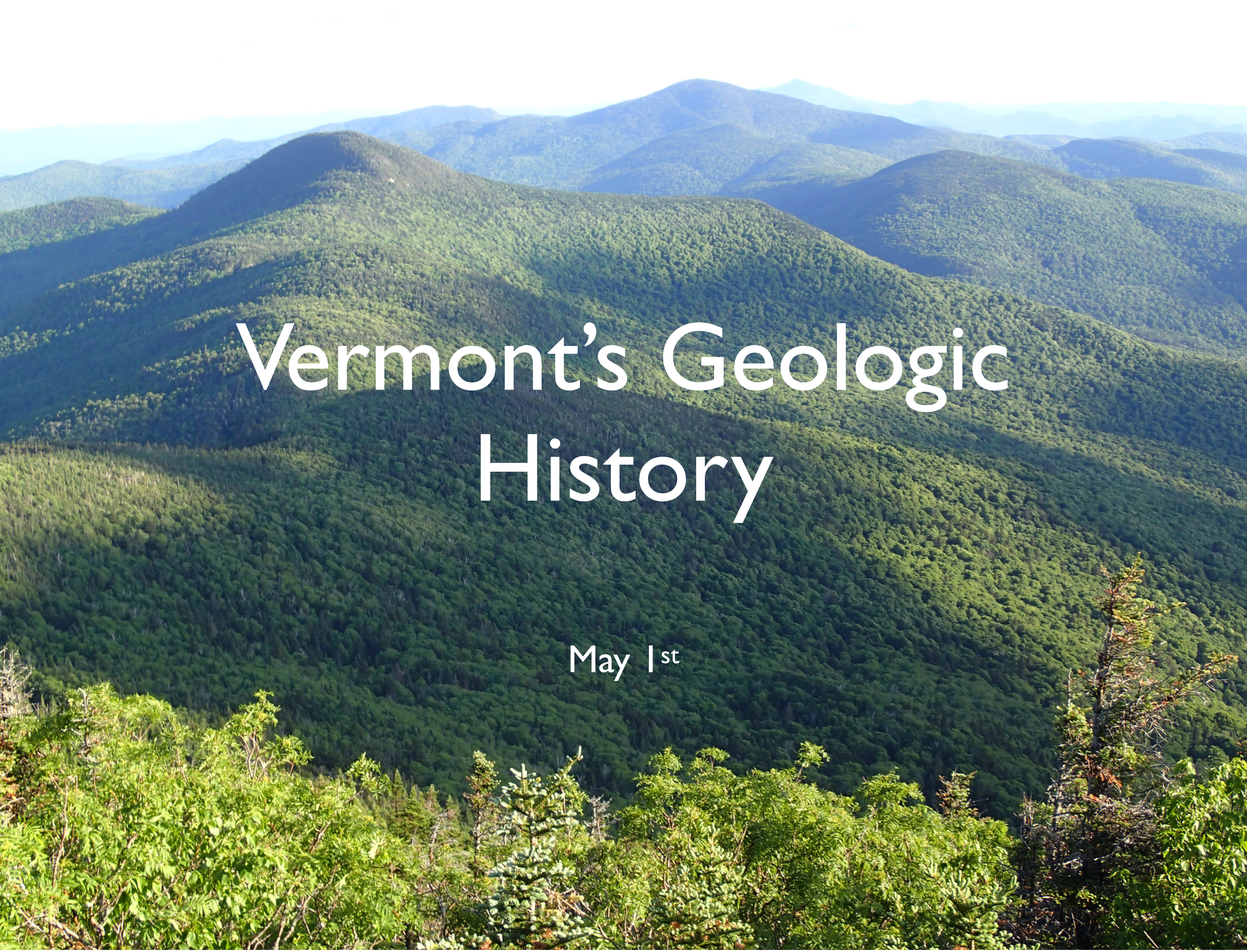
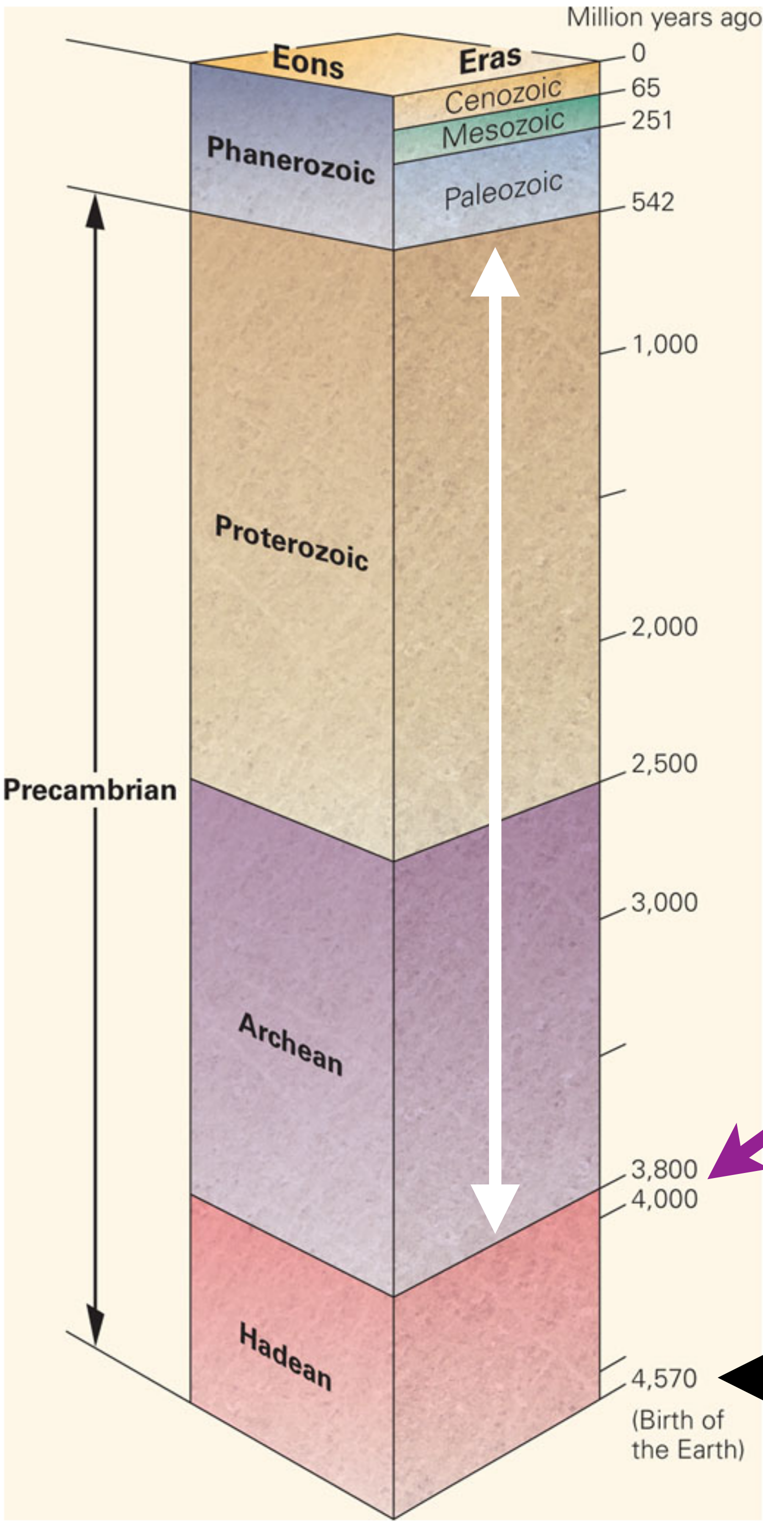


Vermont's Geologic History

May 1st

Earth’s Early History



GEOLOGIC TIME SCALE

One thousand years ago = 1 **Ka**
(Ka stands for kilo-annum)

One million years ago = 1 **Ma**
(Ma stands for mega-annum)

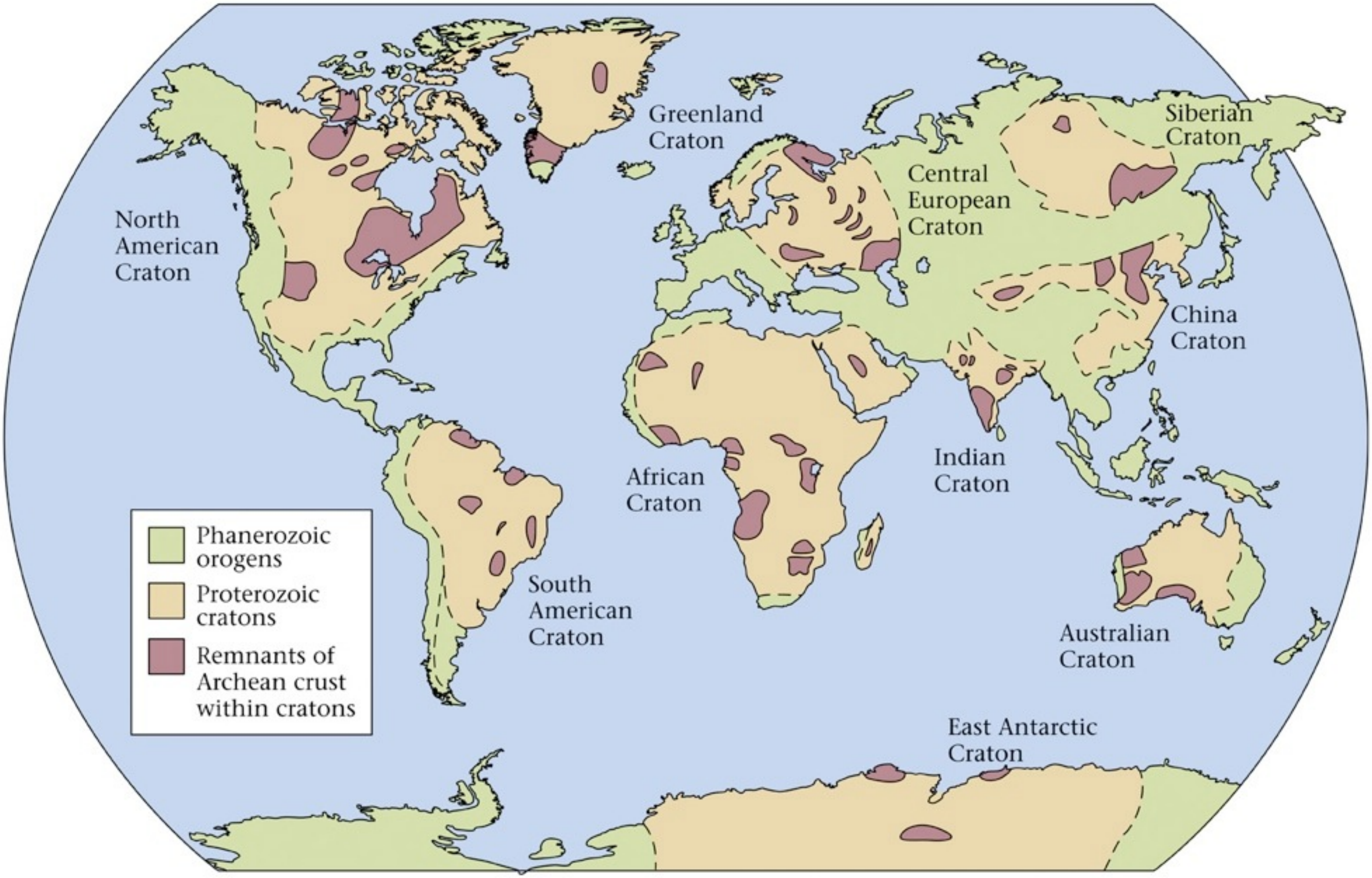
One billion years ago = 1 **Ga**
(Ga stands for giga-annum)

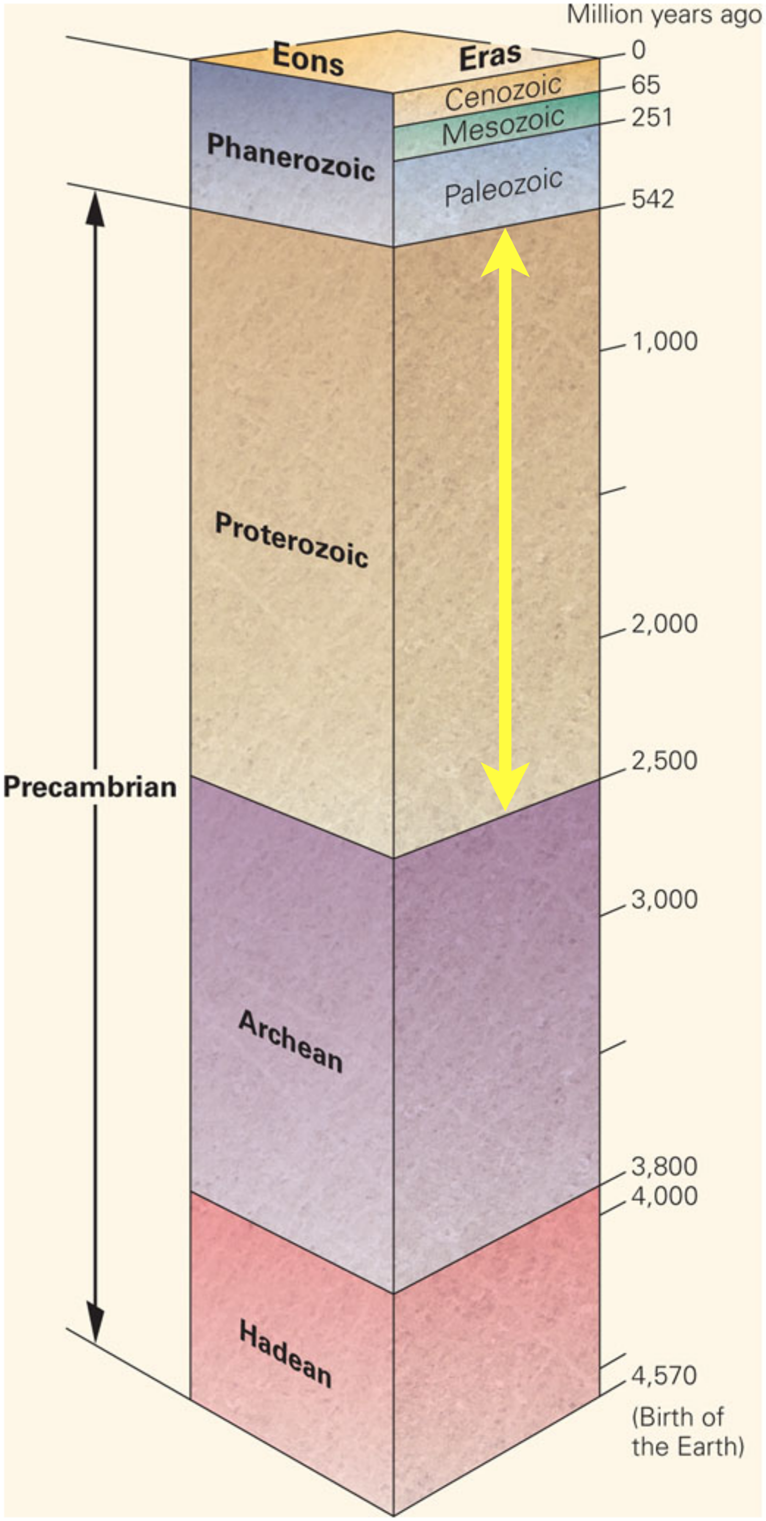
The Archean and Proterozoic Eons make up the bulk of Earth's history

Oldest Rocks Found So Far

The Formation of Earth:
This date comes from rocky meteorites, similar in composition to Earth, that formed ~4.6 Ga (billion years ago).

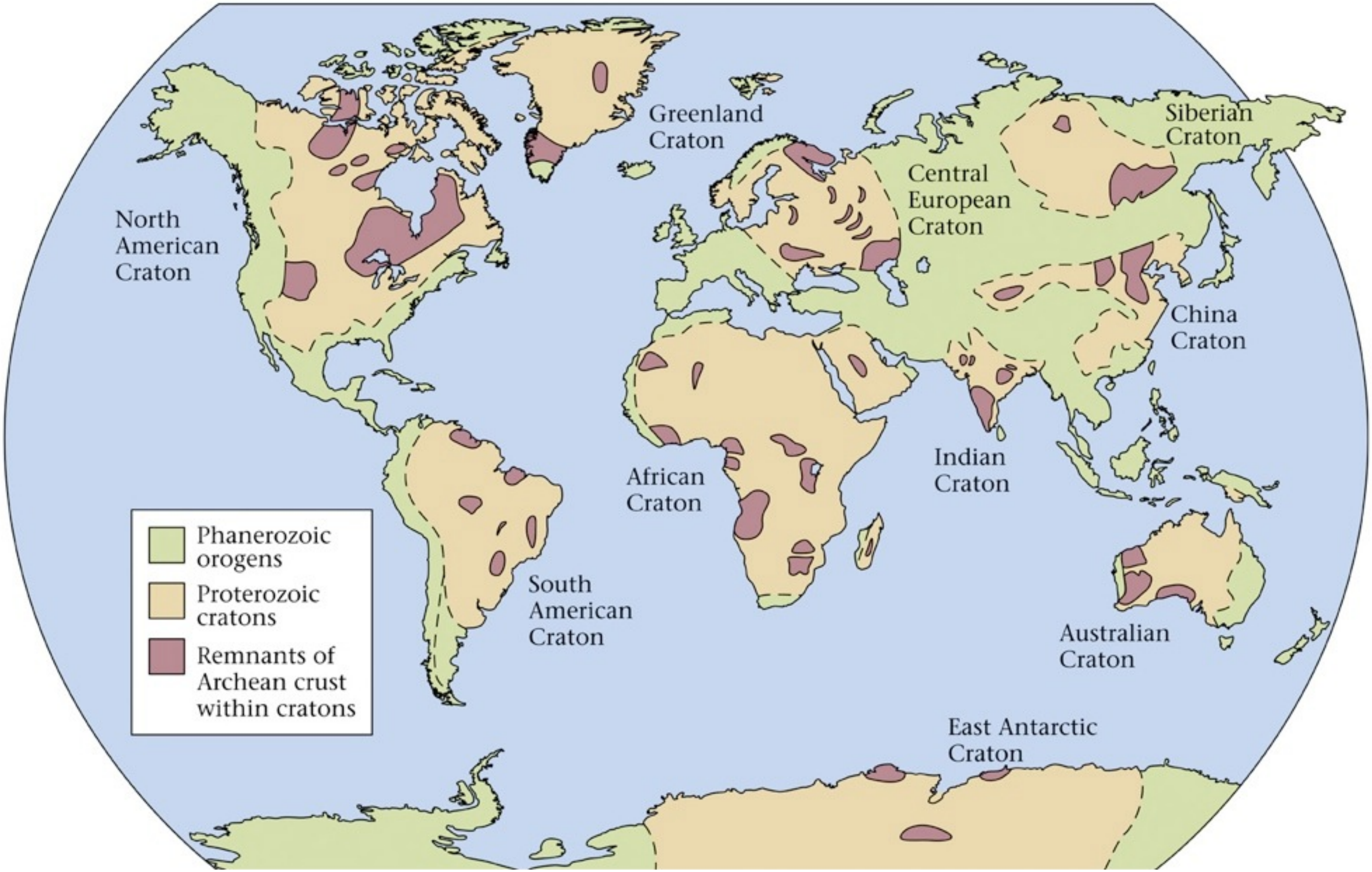
Rocks of Archean Age (3.8–2.5 Ga) occur on every continent.
The closest Archean rocks to us are in northern Minnesota.

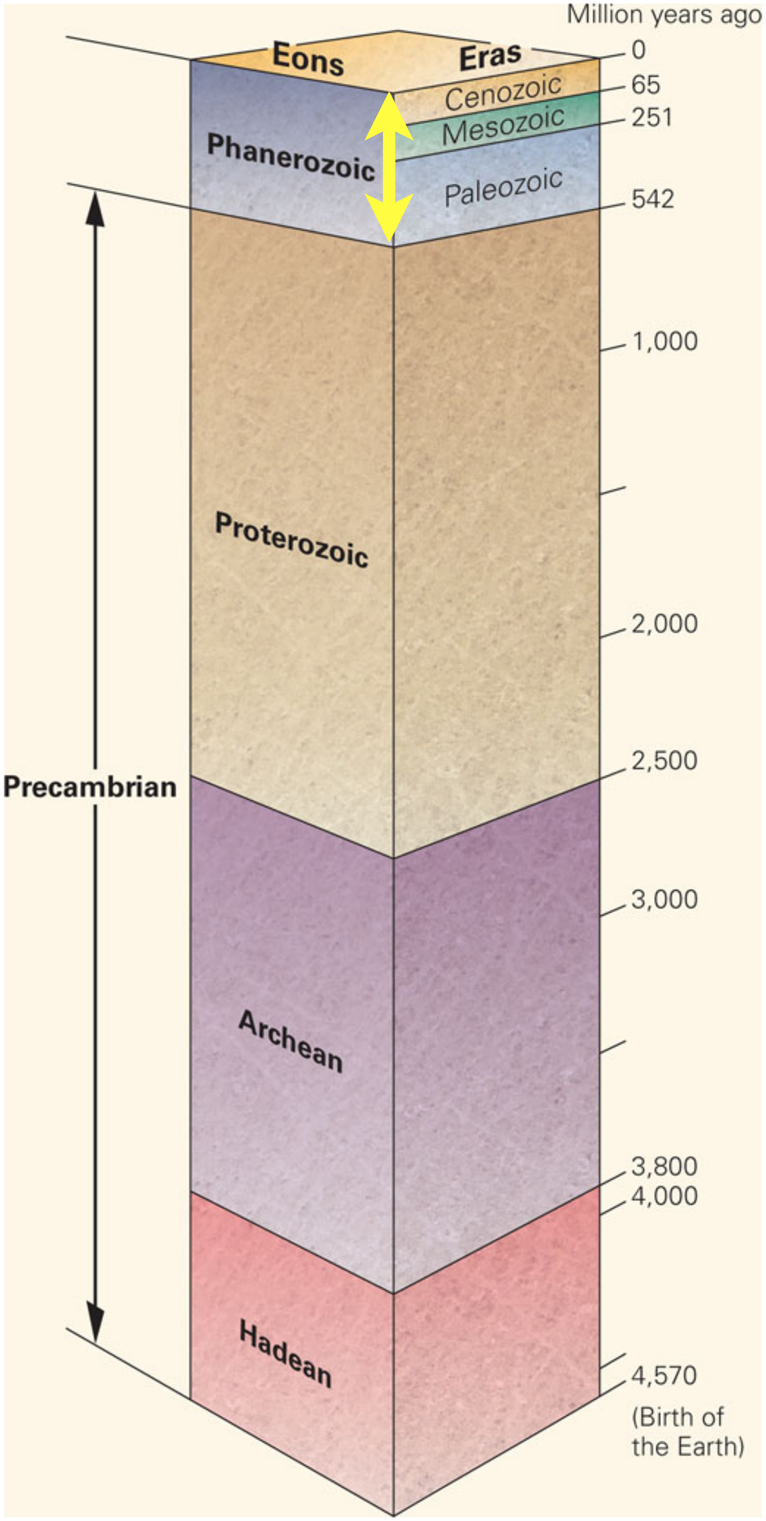




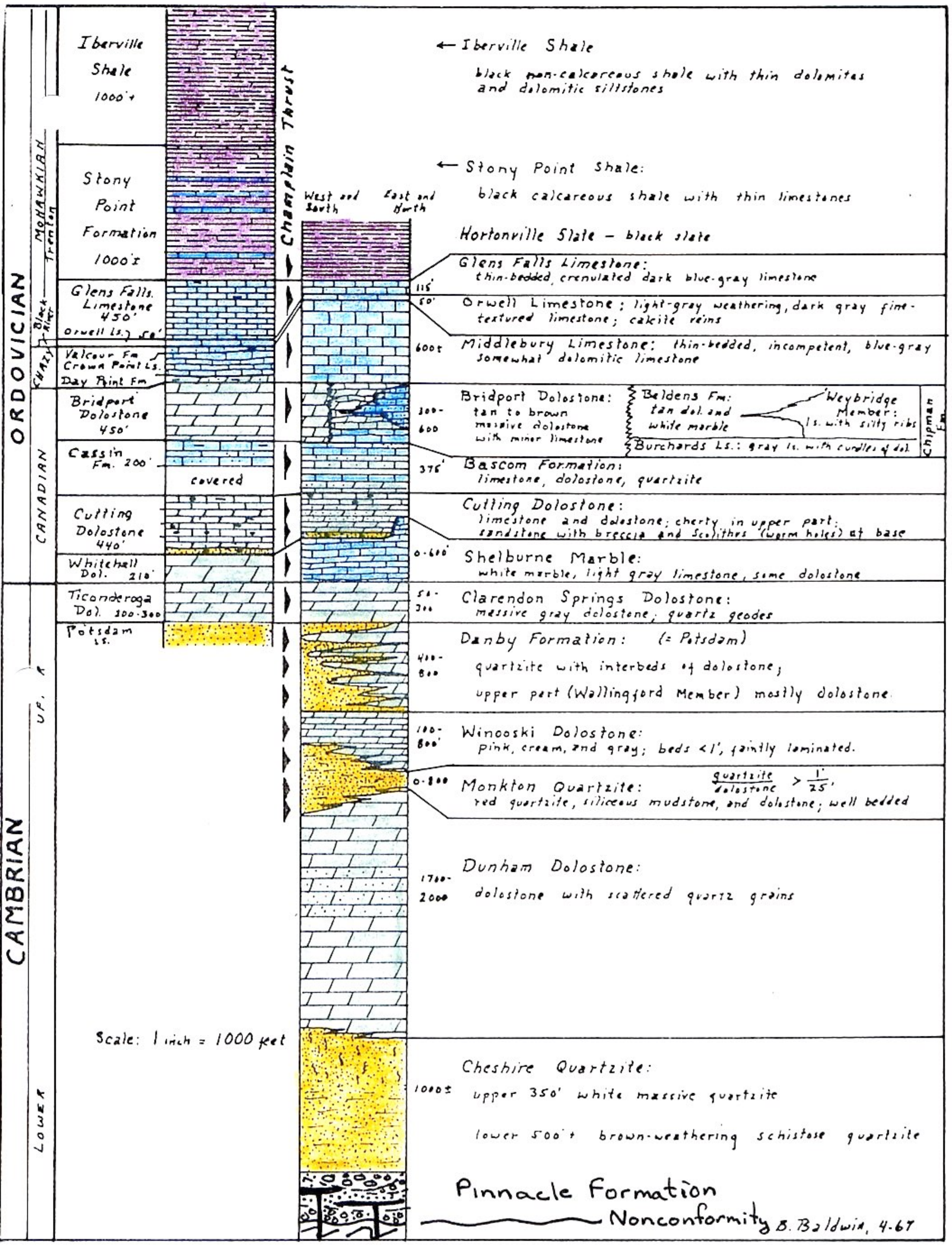
<u>During the Proterozoic Eon (2.5–0.54 Ga) plate tectonic processes similar to those operating today began.</u>

Rocks of Proterozoic Age (2.5–0.54 Ga) make up large parts of the continents. In combination with the older Archean rocks, these old rocks make up the core of most continents.





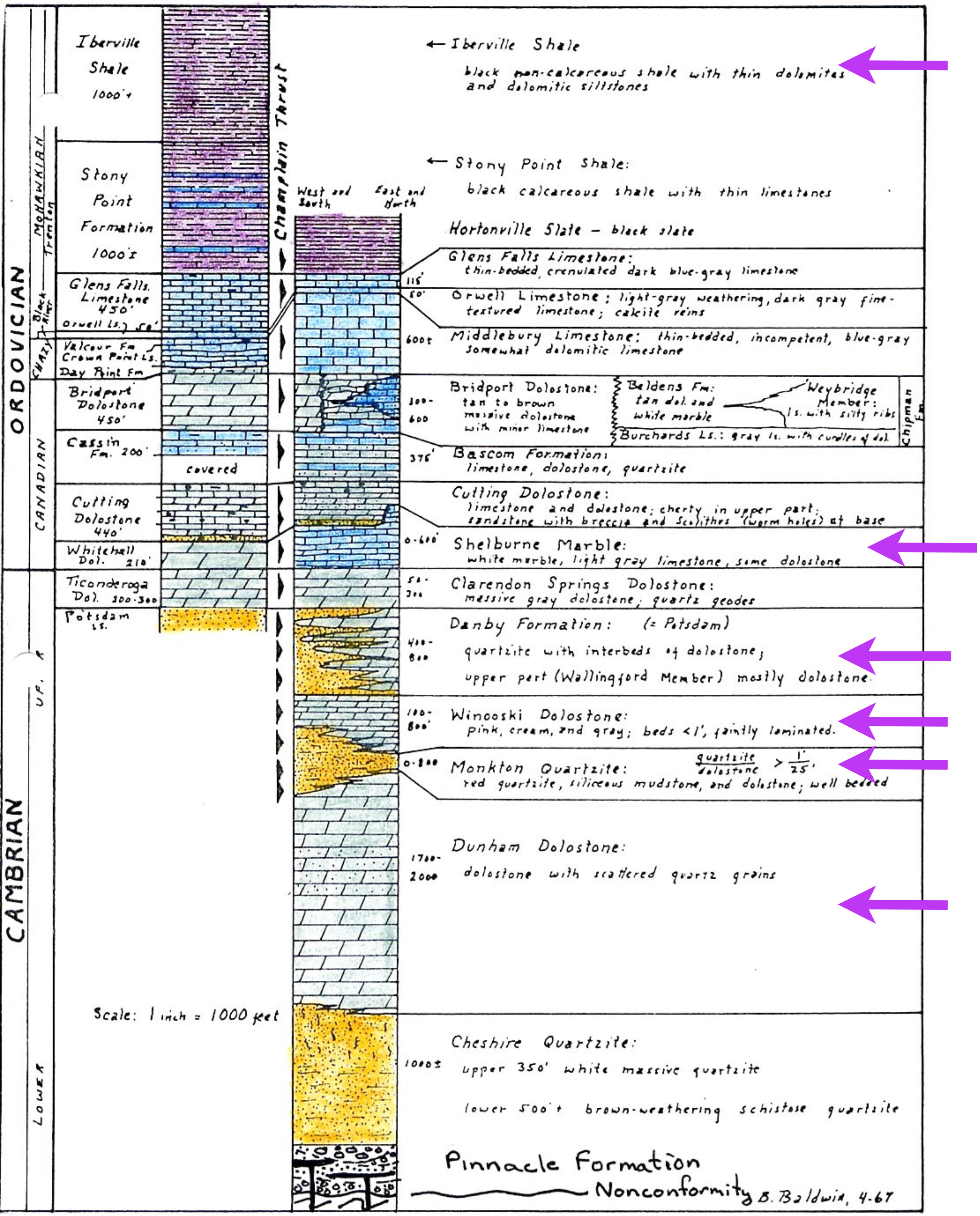
Most rocks in New England formed during the Phanerozoic Eon. This is the time when fossils are abundant and pervasive.



Stratigraphic Column:

Sedimentary rocks occurring in the Champlain Valley are displayed as a vertical stack, oldest at the bottom and youngest at the top.

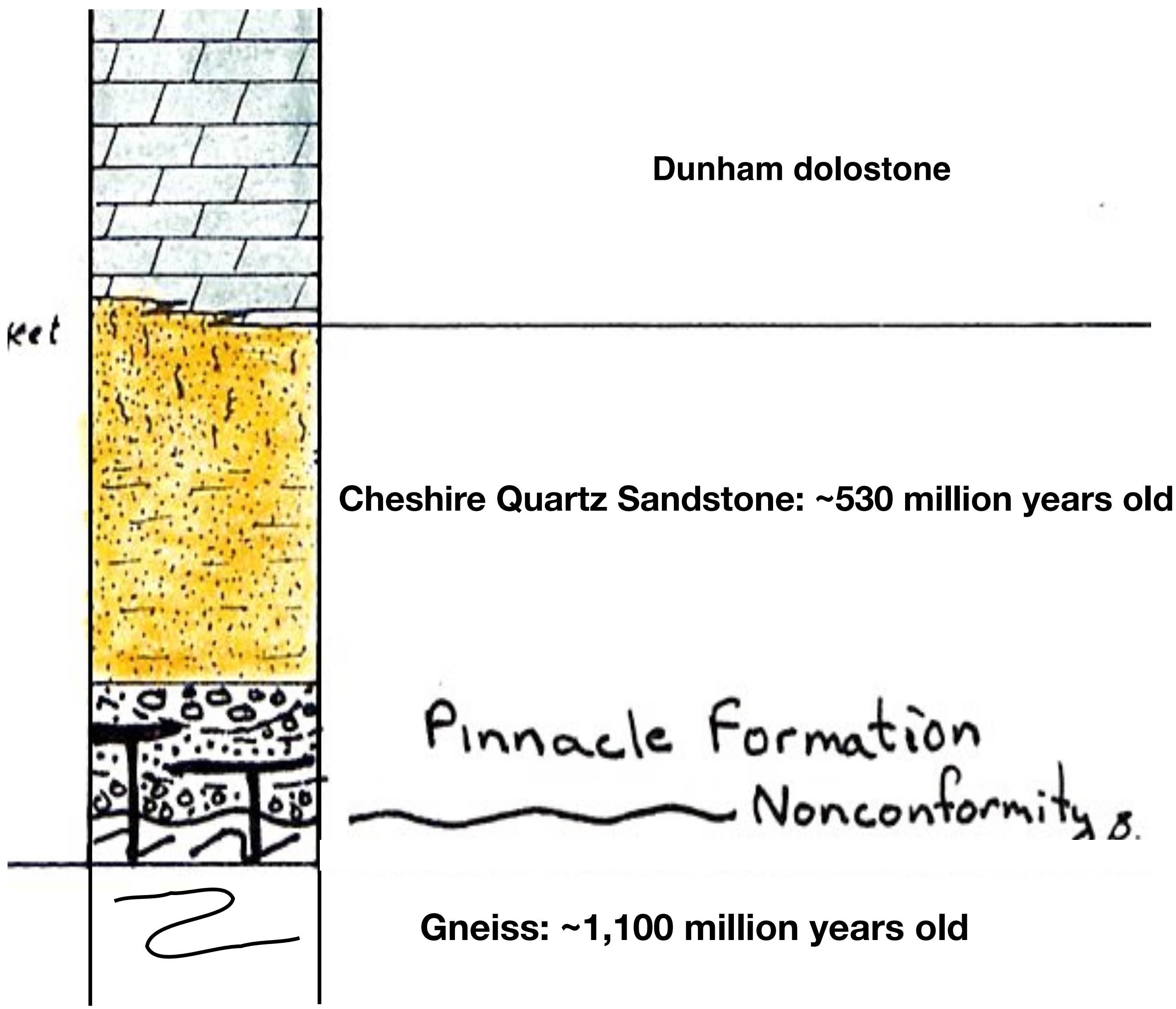
Purple = Shale
Blue = Limestone
Grey = Dolostone
Orange = Sandstone



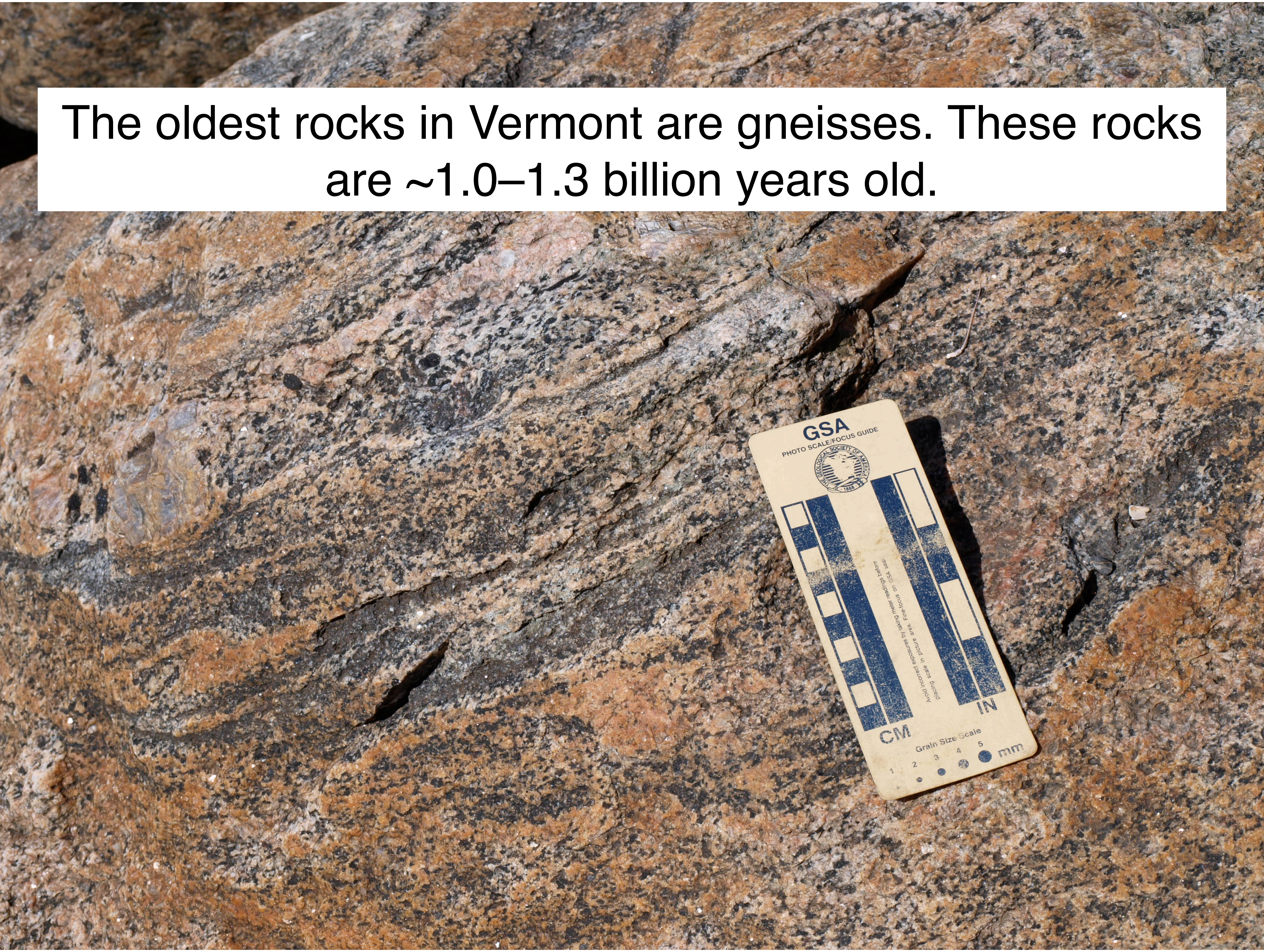
Continuous layers of sedimentary rock consisting of the same type or types of rock are given names, e.g. The “Glens Falls Limestone” or The “Monkton Formation.”

You’ve seen some of these rocks on today’s field trip.

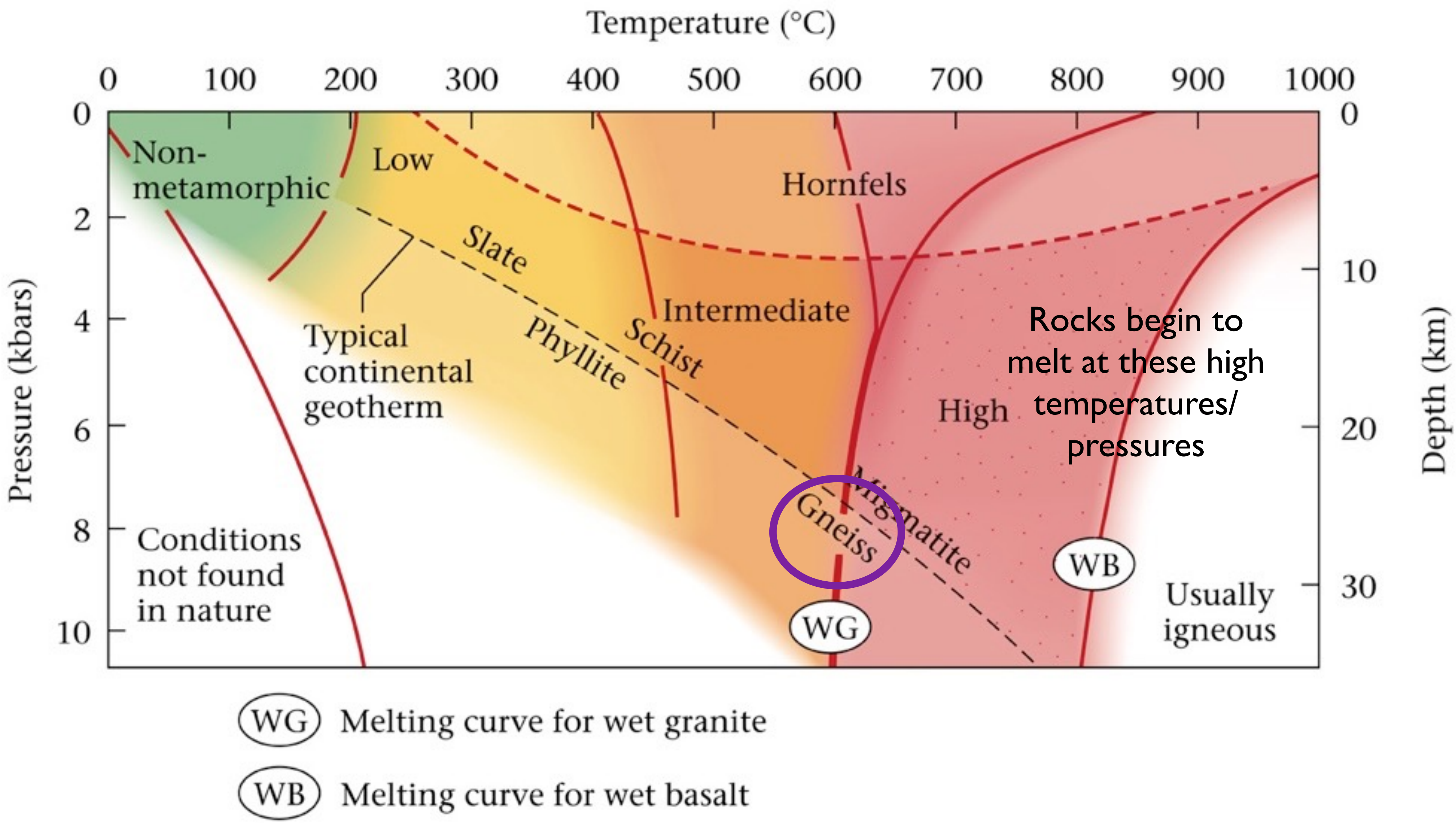
Vermont Geologic History



The oldest rocks in Vermont are gneisses. These rocks are ~1.0–1.3 billion years old.

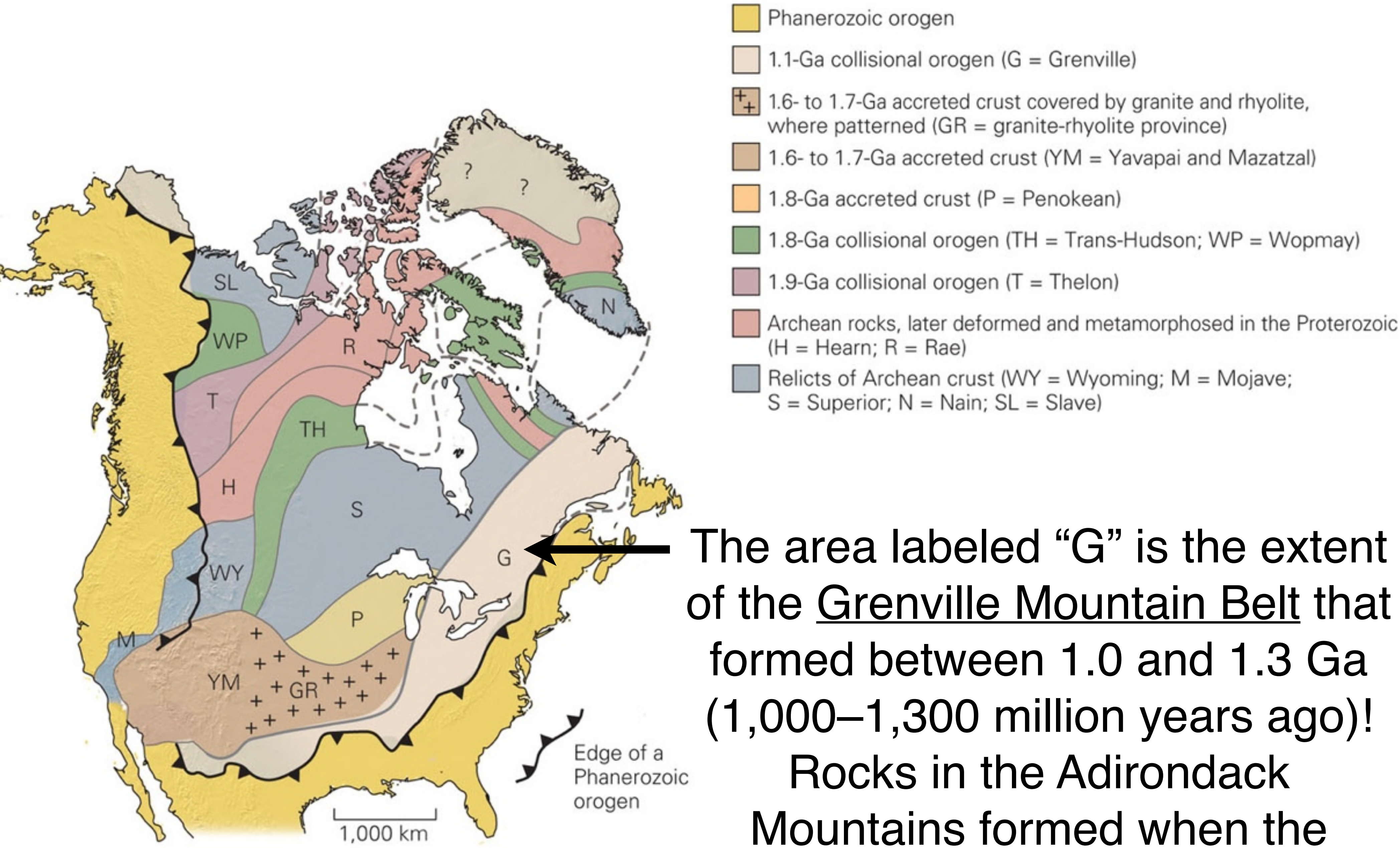


Graph shows the Pressure/Temperature "**environments**" that different metamorphic rocks form in.
Metamorphic Grade (Low-Intermediate-High) describes these different "environments."



Everywhere Grenville rocks are exposed, they consist of gneisses

These rocks were buried under 25–30 km of rock when they were metamorphosed. These are the roots of what was once a very large mountain belt that has eroded away.



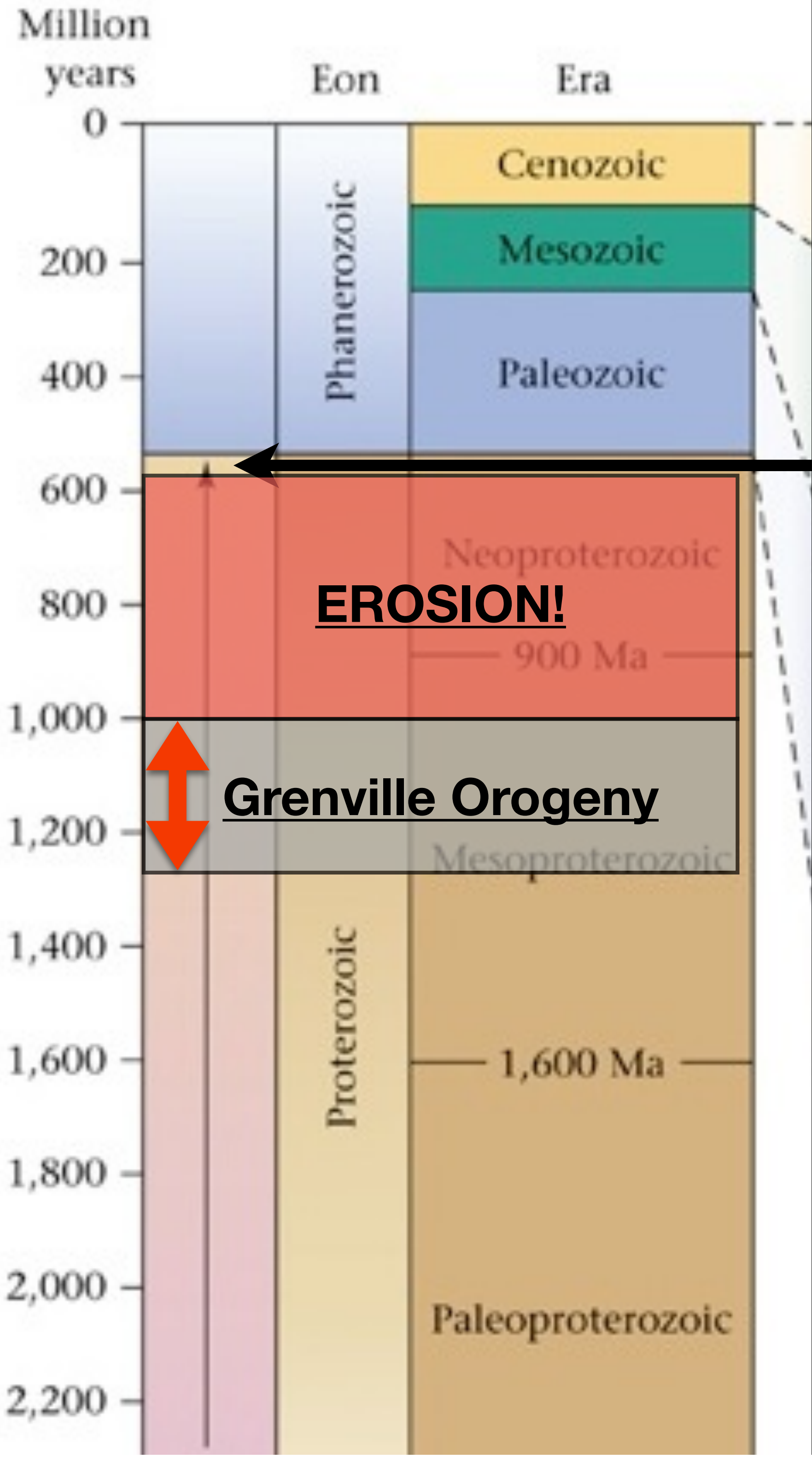
The area labeled "G" is the extent of the Grenville Mountain Belt that formed between 1.0 and 1.3 Ga (1,000–1,300 million years ago)! Rocks in the Adirondack Mountains formed when the Grenville Mountains formed.

The **Grenville Mountains** formed when “South America” collided with the east coast of Laurentia, a continent–continent collision. Think of this mountain belt being on a scale similar to the Himalayan Mountains.

After numerous other plate collisions almost all of the world’s continents were amalgamated together in a large “supercontinent” called **Rodinia**.
This map shows a reconstruction of Rodinia ~750 million years ago. **Laurentia** is the name given to the old “core” of North America.

Where are Grenville-age rocks found today?

- In younger mountain belts where they have been carried upwards along faults
  - The Adirondack Mountains
  - The core of the southern Green Mountains
  - The Hudson Highlands & western Connecticut
  - The Blue Ridge
- The Laurentian Mountains north of Montréal
- *Under our feet, buried under ~3,000 m of sedimentary rocks!*



The first sedimentary rocks in the Champlain Valley were deposited 550–600 Ma (million years ago) close to the start of the Phanerozoic Eon.

<u>The Grenville mountains eroded for >400 million years before sediments were deposited in the Champlain Valley.</u>

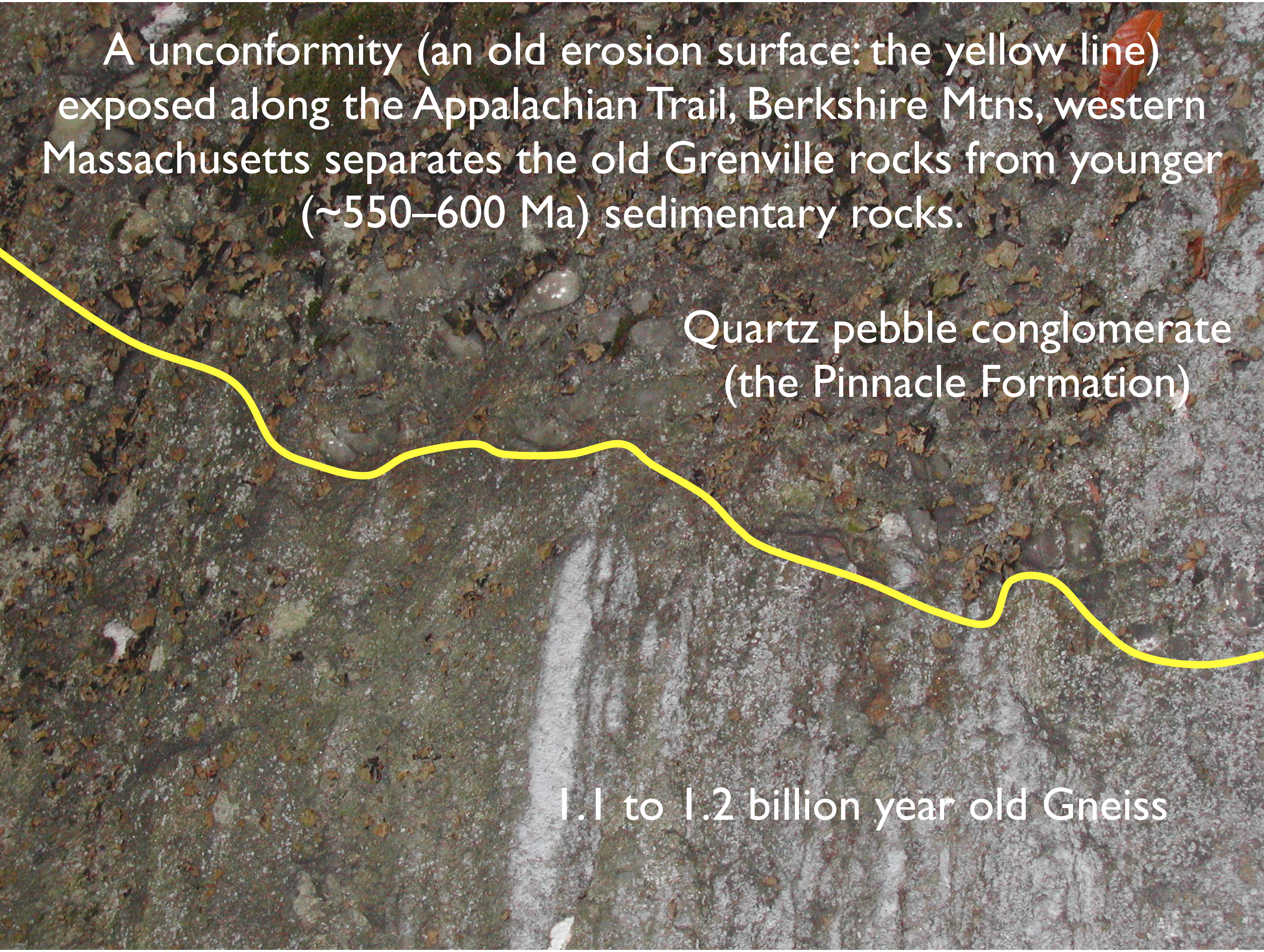
<u>Erosion Rate:</u>

30 km/400 million years

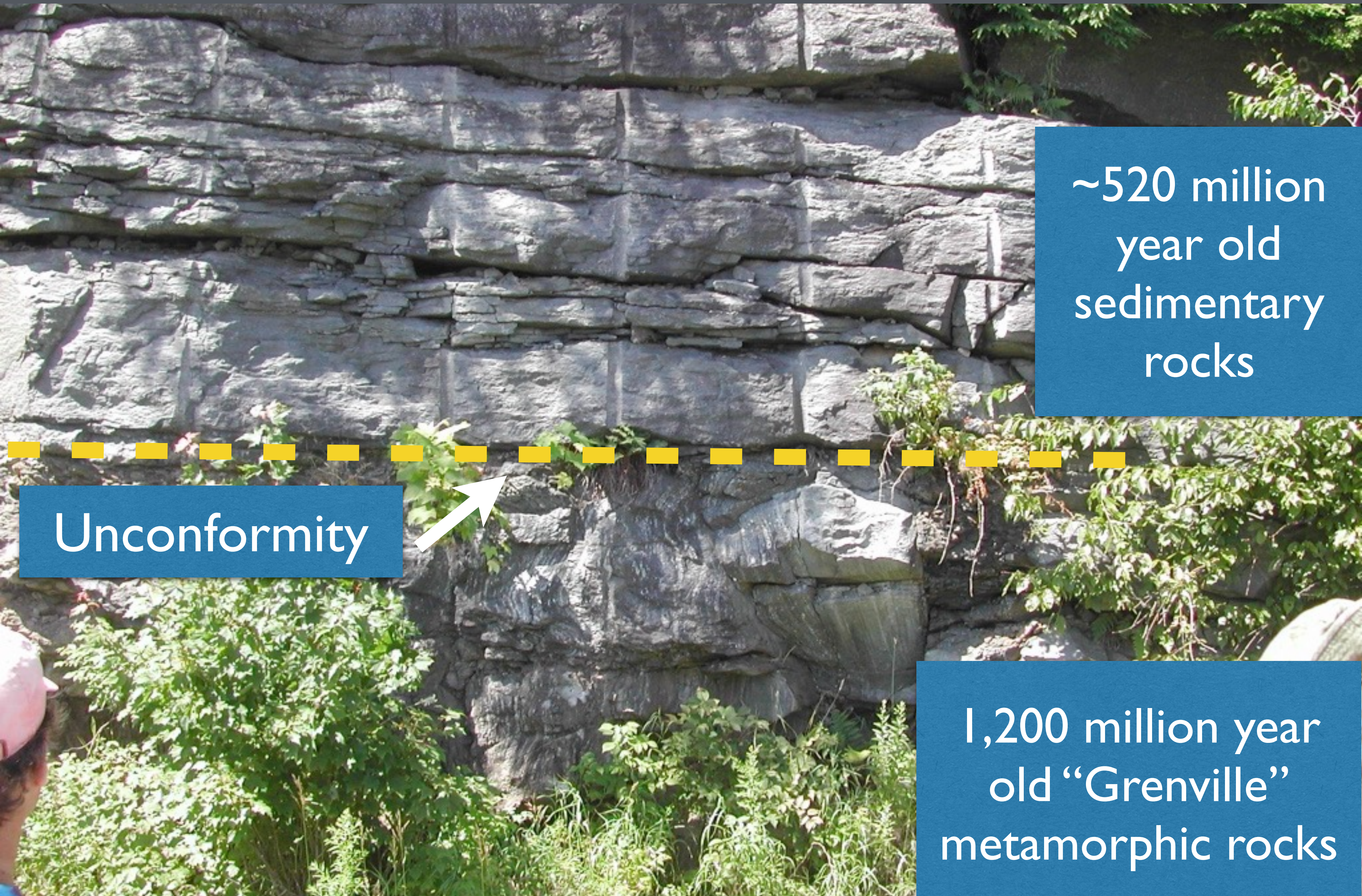
30 x 10^6 mm/400 x 10^6 years

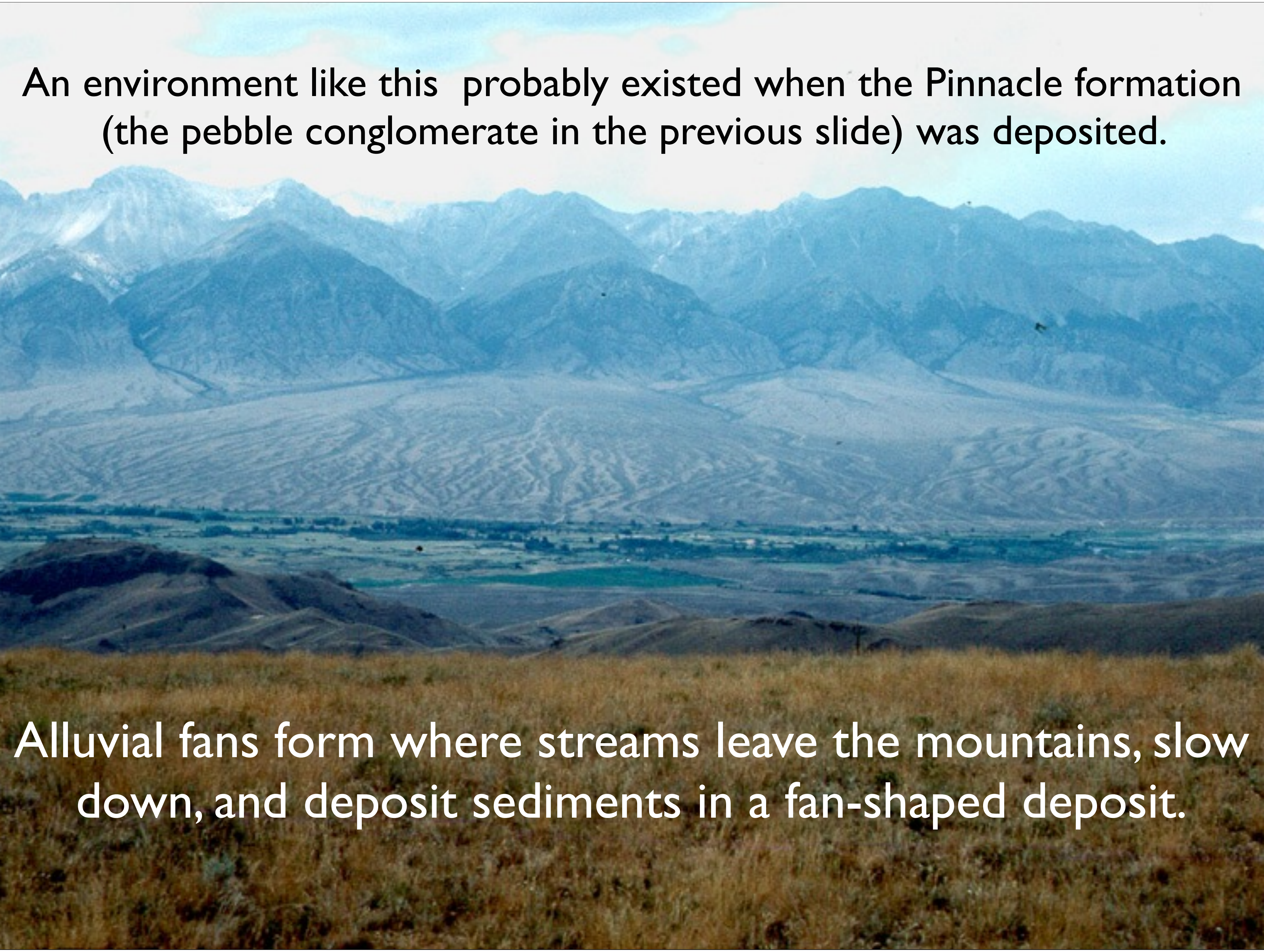
30 mm/400 years

0.075 mm/year

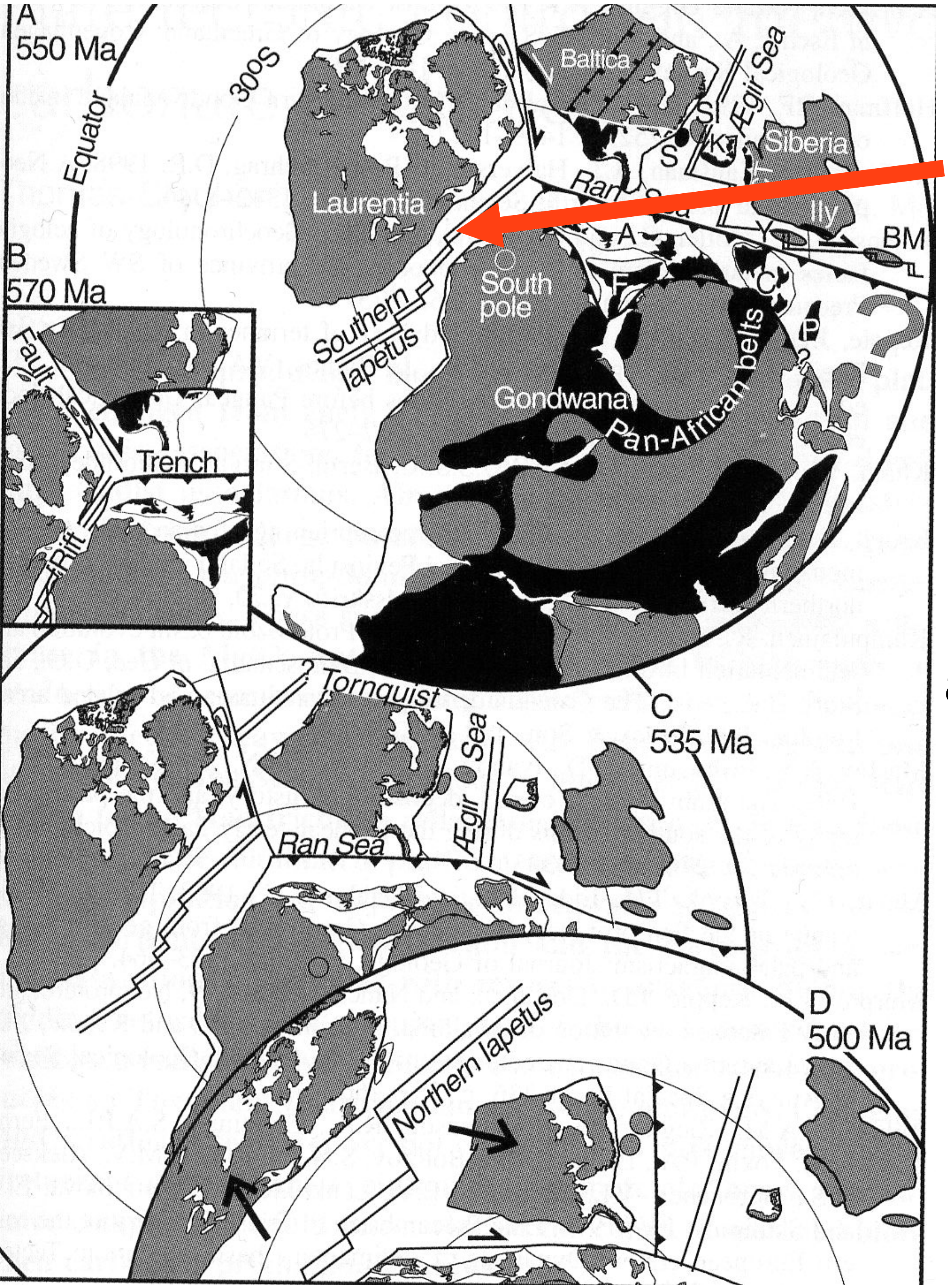

A unconformity (an old erosion surface: the yellow line) exposed along the Appalachian Trail, Berkshire Mtns, western Massachusetts separates the old Grenville rocks from younger (~550–600 Ma) sedimentary rocks.
Quartz pebble conglomerate (the Pinnacle Formation)
1.1 to 1.2 billion year old Gneiss

The same old erosion surface (unconformity) exposed north of Whitehall, New York.




An environment like this probably existed when the Pinnacle formation (the pebble conglomerate in the previous slide) was deposited.
Alluvial fans form where streams leave the mountains, slow down, and deposit sediments in a fan-shaped deposit.

In other areas an environment like this, with river channels, bars, and floodplains existed when the Pinnacle formation was deposited, but without the trees—land plants hadn't evolved yet!

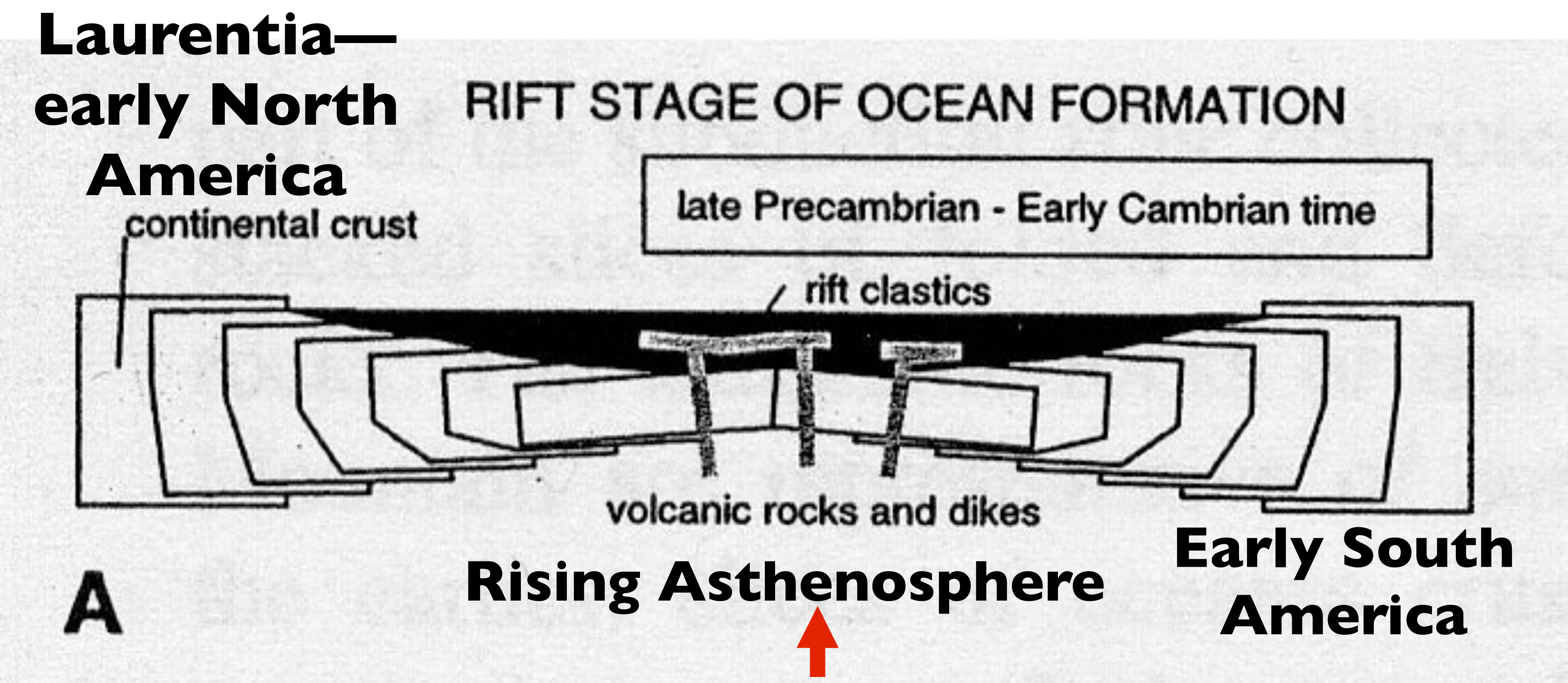


Continental rifting

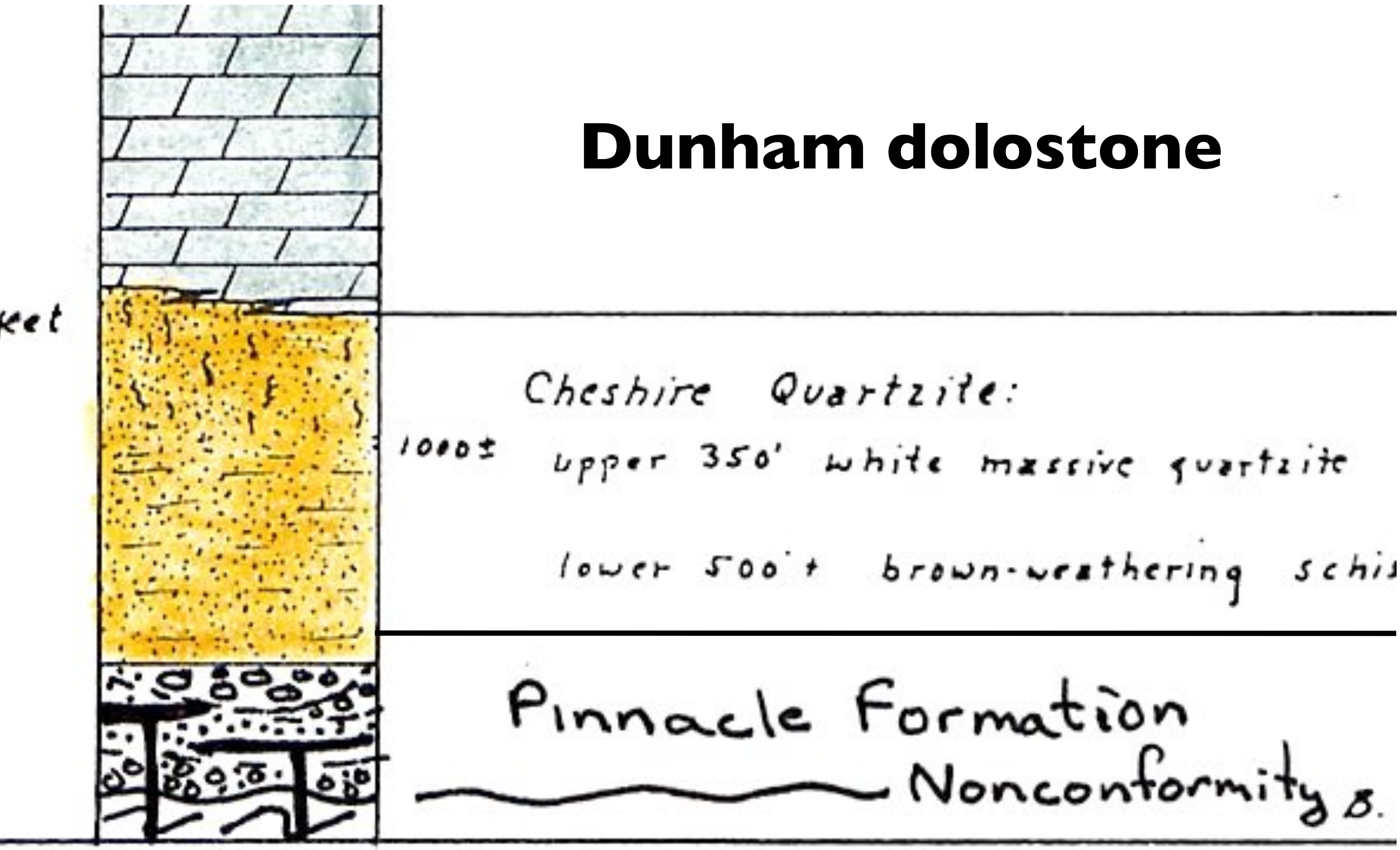
Map shows the configuration of the continents during the breakup (rifting) of **Rodinia** (the continent that formed after the Grenville Orogeny). When Laurentia rifted apart from the rest of Rodinia a new ocean formed, the **Iapetus Ocean** (Hartz and Torsvik, 2002).

Initial Rifting (~ 600–550 Ma)

When Rodinia began to rift apart a Rift Basin formed which was filled in by stream sediments (“Rift Clastics”: Pinnacle Formation) and volcanic rocks. This is similar to what is occurring today in the East African rift. During rifting, the Continental lithosphere thins.



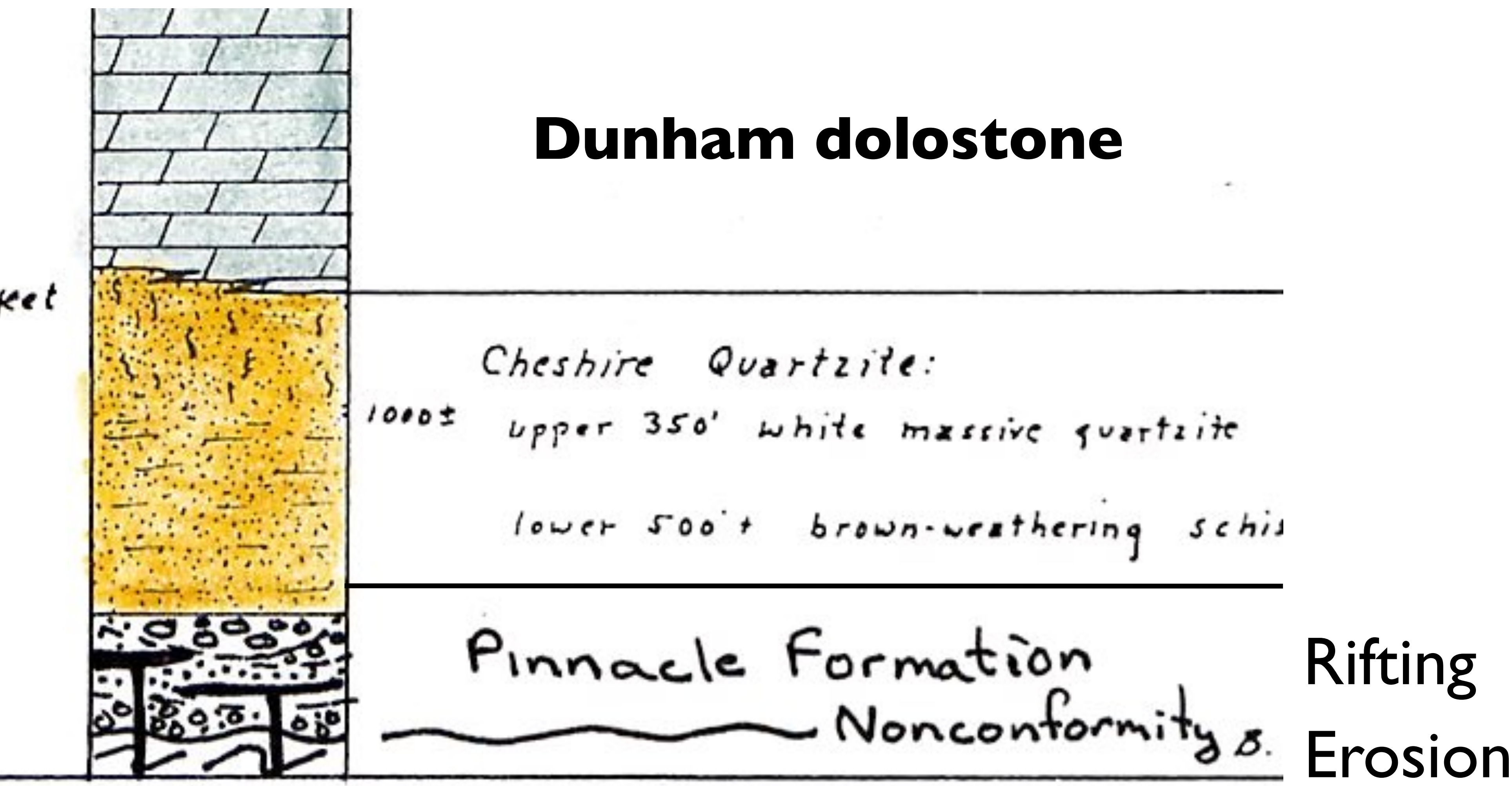
The **Cheshire Formation** (mostly sandstone) was deposited on top of the Pinnacle formation. These sandstones formed along beaches or barrier islands along the shore of the newly formed Iapetus Ocean.



Rifting
Erosion

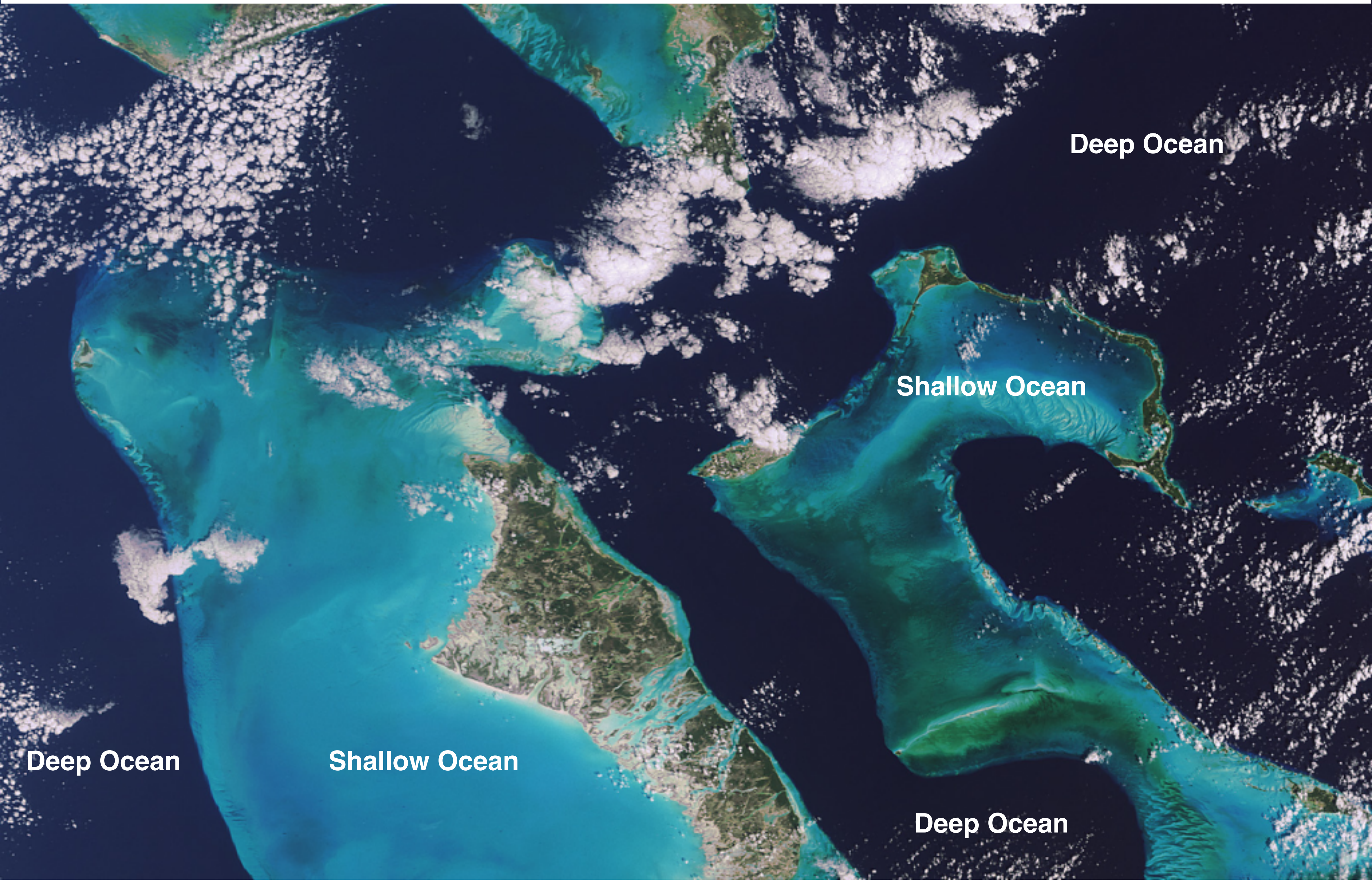
Old Grenville Rocks below the nonconformity

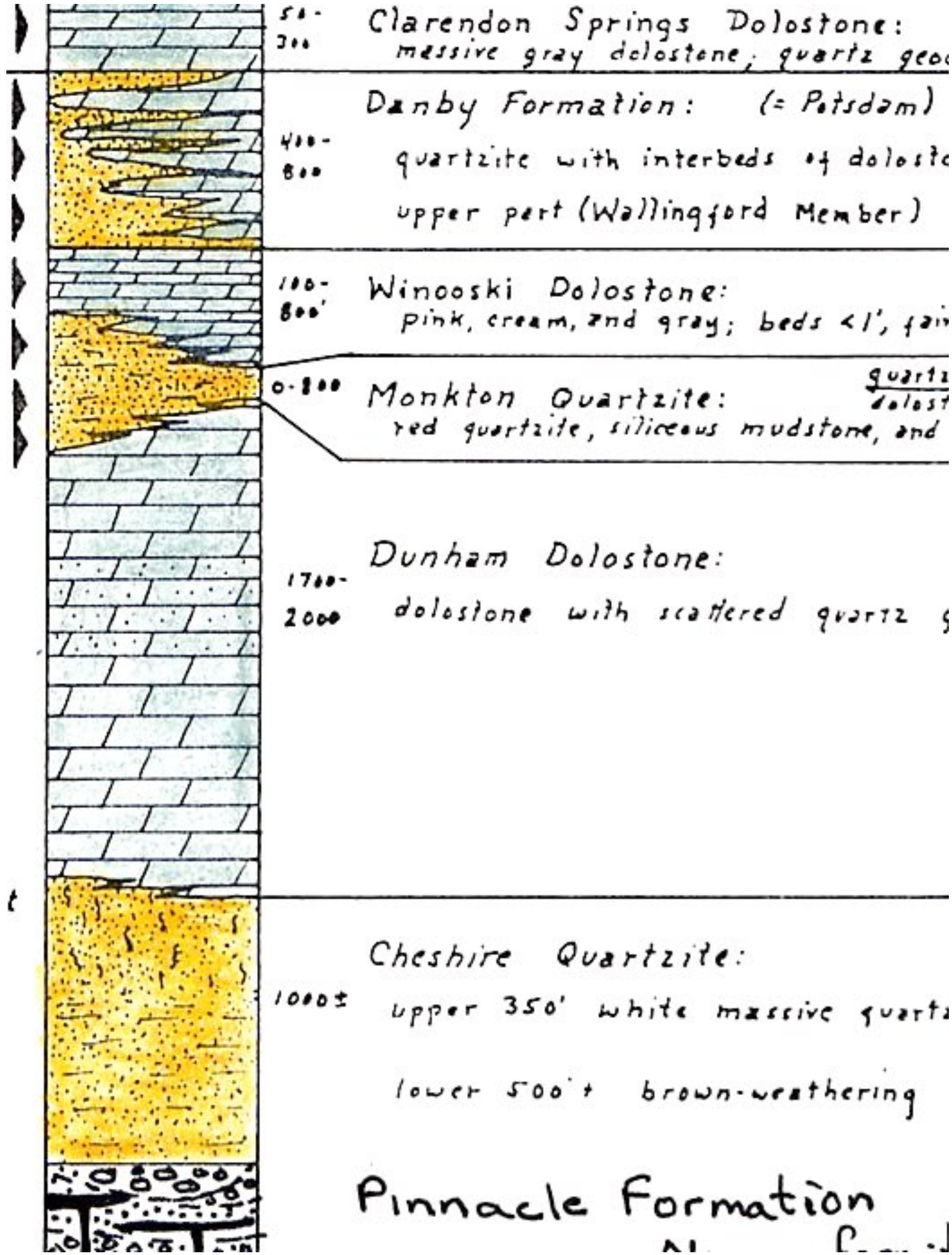
The **Dunham Dolostone** was deposited on top of the Cheshire Quartz Sandstone.



Old Grenville Rocks below the nonconformity

The calcite/dolomite making up limestone and dolostone was precipitated from organisms living in a shallow, warm ocean, similar to the Bahamas.

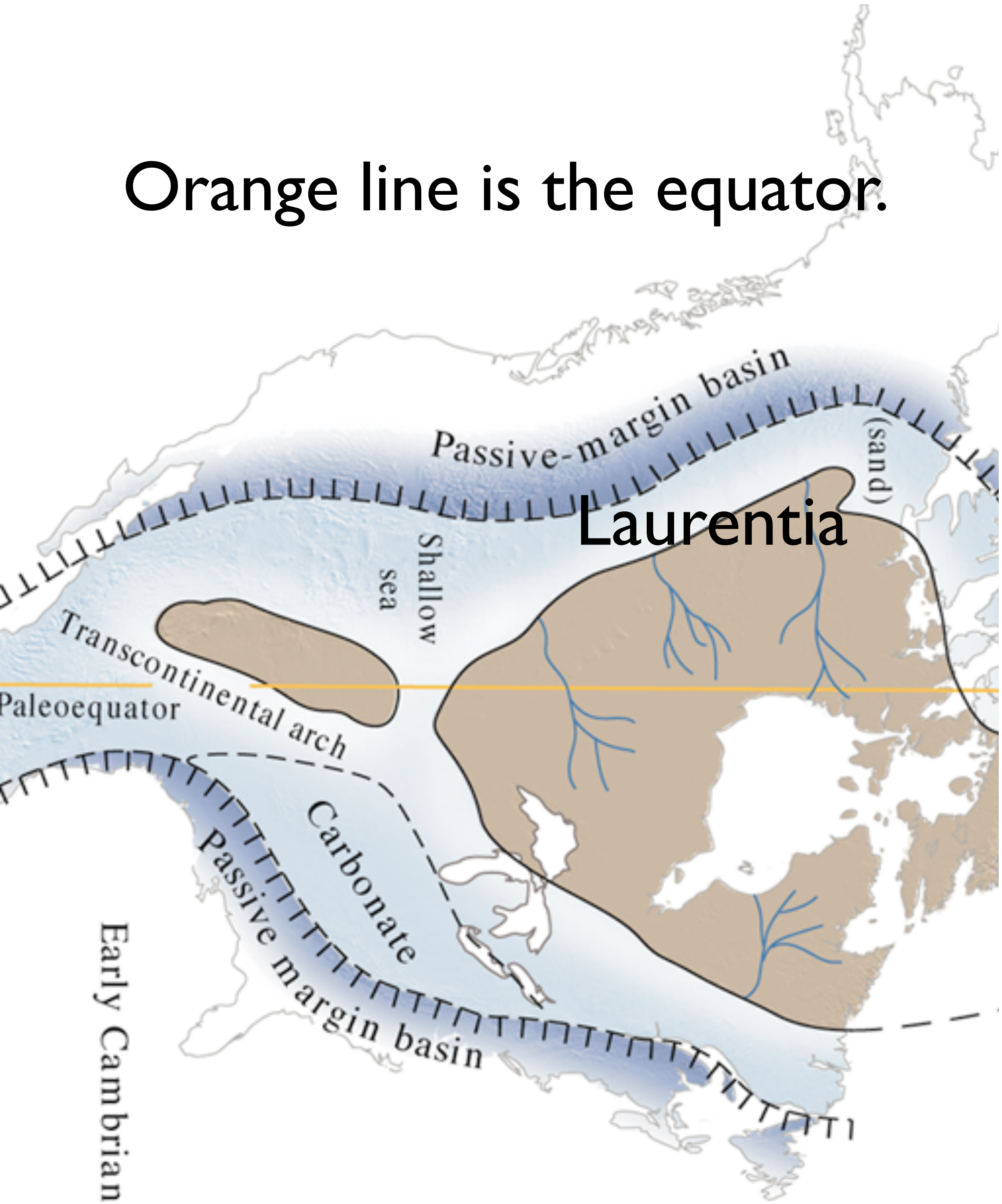




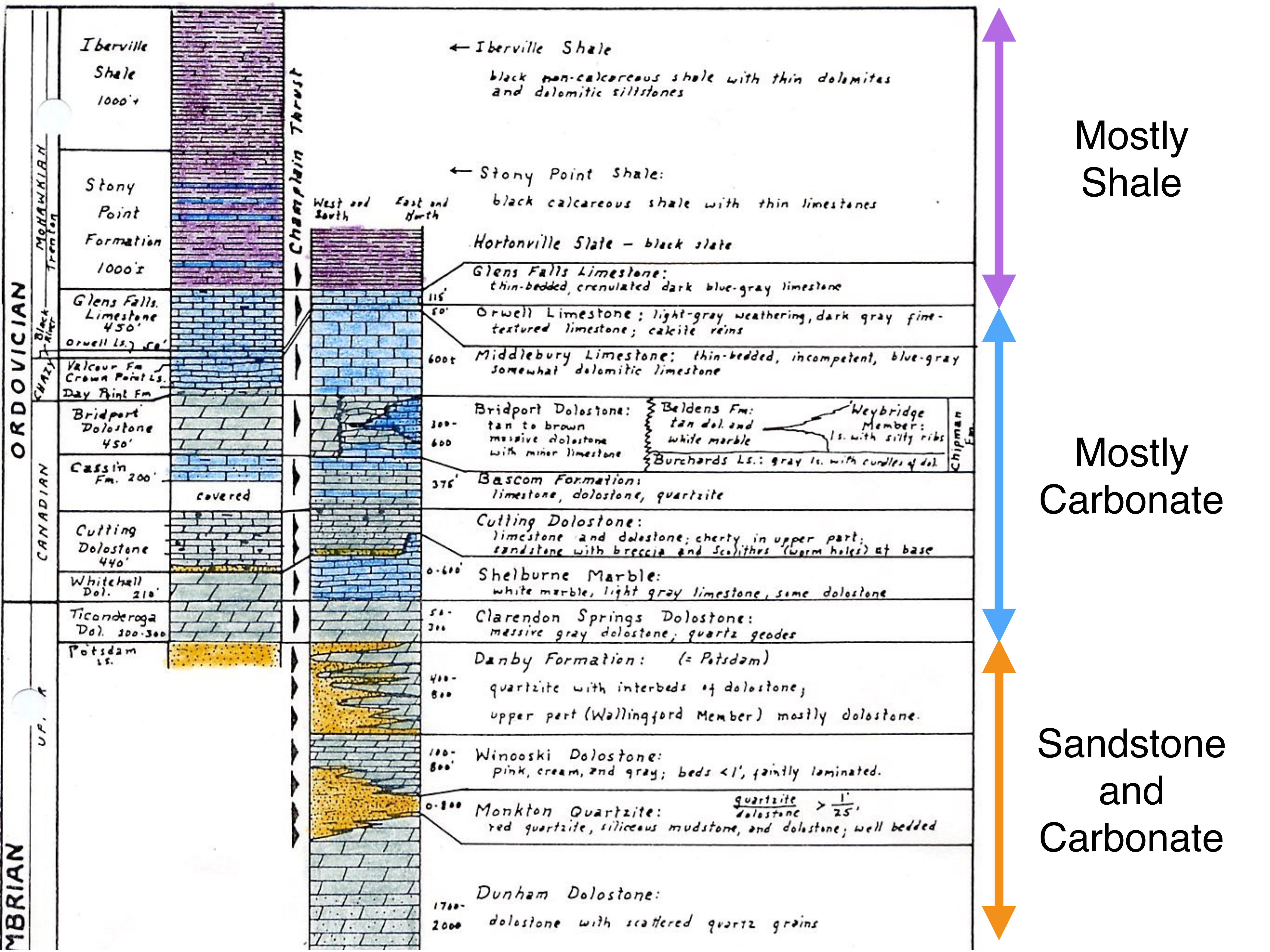
Sandstone and mud was deposited when the Monkton Formation was deposited. During this time sea level fell bringing the shoreline of the Iapetus ocean to areas that previously had been too far away from shore to receive any sand or mud.

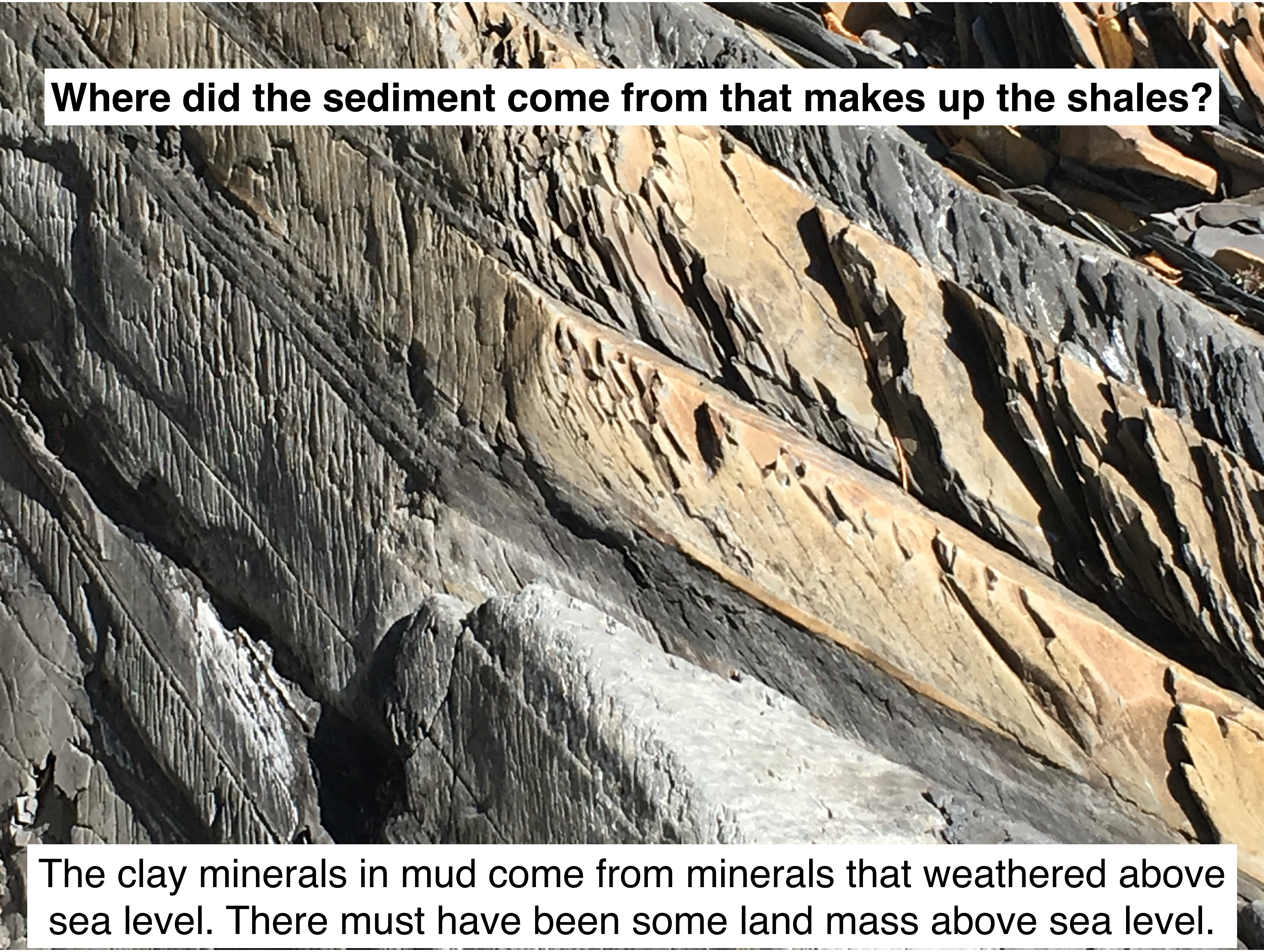
Sea level rose again when the Winooski Dolostone was deposited (no sand or mud in this rock, fell when the Danby Formation was deposited, and then rose again when the Clarendon Springs Dolostone was deposited.

Orange line is the equator.

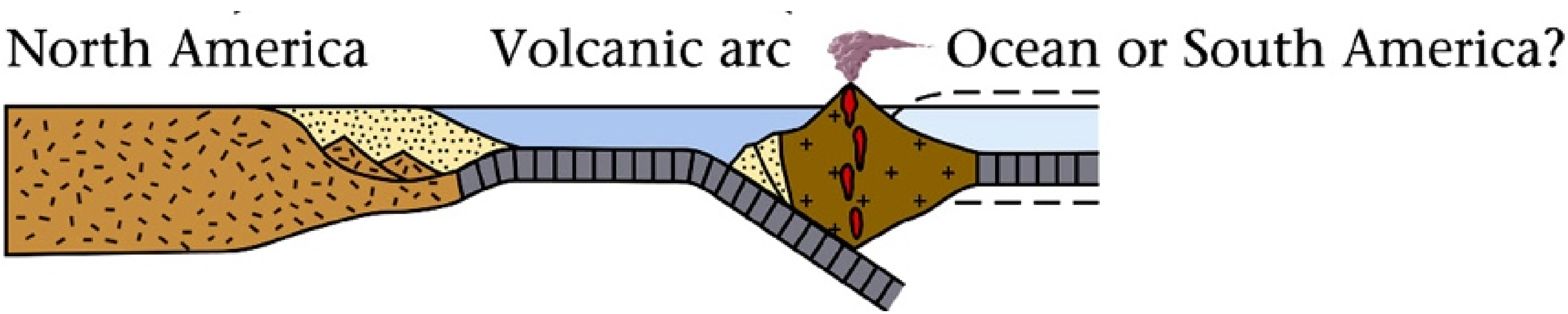


- Eventually the Iapetus Ocean transgressed across much of Laurentia.
- Across this continental area, the Iapetus ocean was shallow (sunlight reached the bottom) and warm (close to the equator); a good environment for limestone deposition.
- The Grenville Mountain belt had eroded away by this time, i.e. there were no Appalachian mountains—yet!

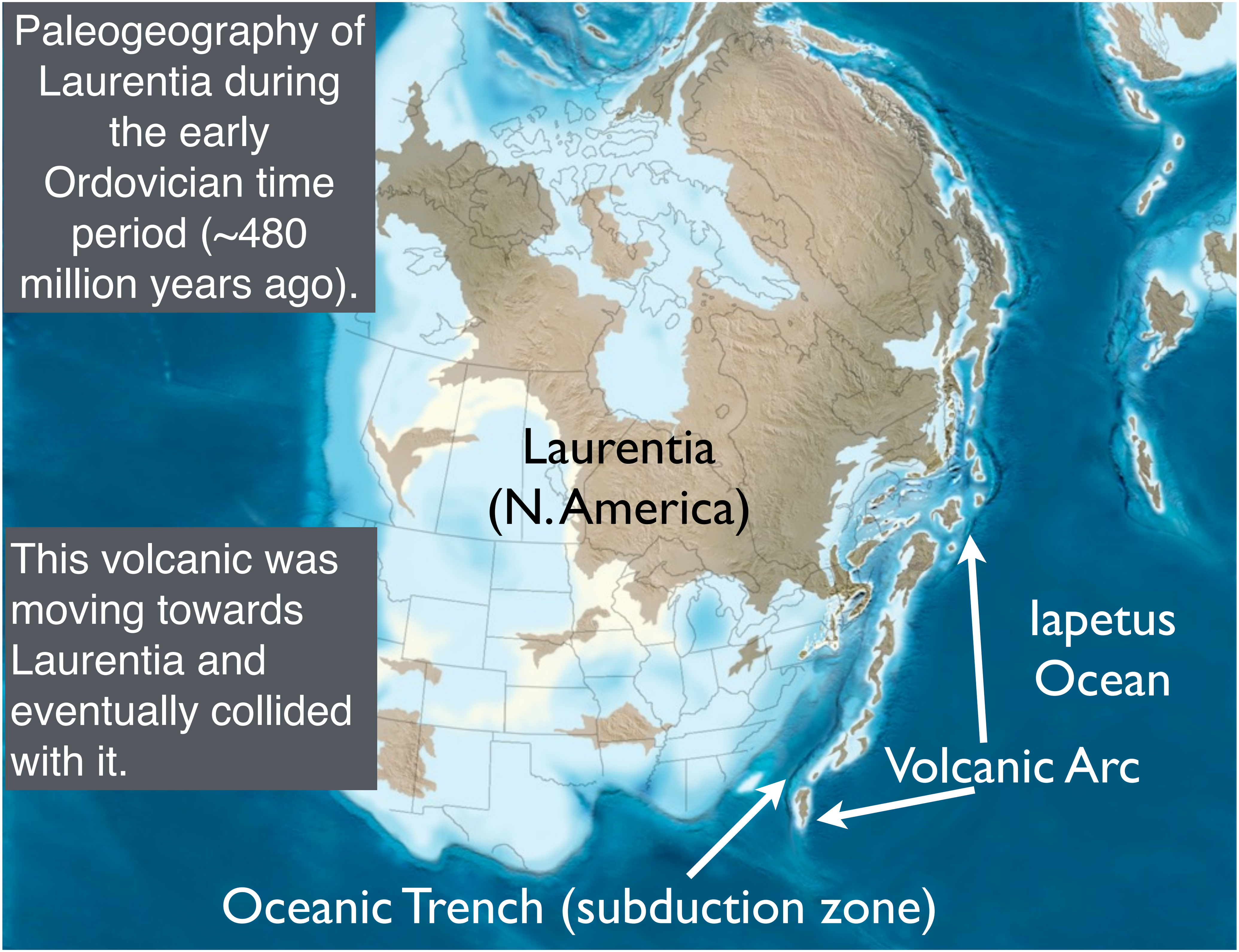

ORDOVICIAN
MBRIAN
MOHAWKIAN
Trenton
Black River
CHAZY
CANADIAN
Iberville Shale 1000'+
Stony Point Formation 1000'±
Glens Falls Limestone 450'
Orwell Ls. 50'
Valcour Fm
Crown Point Ls.
Day Point Fm
Bridport Dolostone 450'
Cassin Fm. 200'
covered
Cutting Dolostone 440'
Whitehall Dol. 210'
Ticonderoga Dol. 200-300
Potsdam ss.
Champlain Thrust
West and South
East and North
← Iberville Shale
black non-calcareous shale with thin dolomites and dolomitic siltstones
← Stony Point Shale:
black calcareous shale with thin limestones
Hortonville Slate – black slate
Glens Falls Limestone:
thin-bedded, crenulated dark blue-gray limestone
115'
Orwell Limestone: light-gray weathering, dark gray fine-textured limestone; calcite veins
50'
Middlebury Limestone: thin-bedded, incompetent, blue-gray somewhat dolomitic limestone
600±
Bridport Dolostone:
tan to brown massive dolostone with minor limestone
300-600
Beldens Fm:
tan dol. and white marble
Weybridge Member:
ls. with silty ribs
Burchards Ls.: gray ls. with curdles of dol.
Chipman Fm
Bascom Formation:
limestone, dolostone, quartzite
375'
Cutting Dolostone:
limestone and dolostone; cherty in upper part; sandstone with breccia and Scolithes (worm holes) at base
Shelburne Marble:
white marble, light gray limestone, some dolostone
0-600'
Clarendon Springs Dolostone:
massive gray dolostone; quartz geodes
50-300
Danby Formation: (= Potsdam)
quartzite with interbeds of dolostone;
upper part (Wallingford Member) mostly dolostone.
400-800
Winooski Dolostone:
pink, cream, and gray; beds <1', faintly laminated.
100-800'
Monkton Quartzite: quartzite / dolostone > 1/25
red quartzite, siliceous mudstone, and dolostone; well bedded
0-800
Dunham Dolostone:
dolostone with scattered quartz grains
1700-2000
Mostly Shale
Mostly Carbonate
Sandstone and Carbonate


Where did the sediment come from that makes up the shales?
The clay minerals in mud come from minerals that weathered above sea level. There must have been some land mass above sea level.

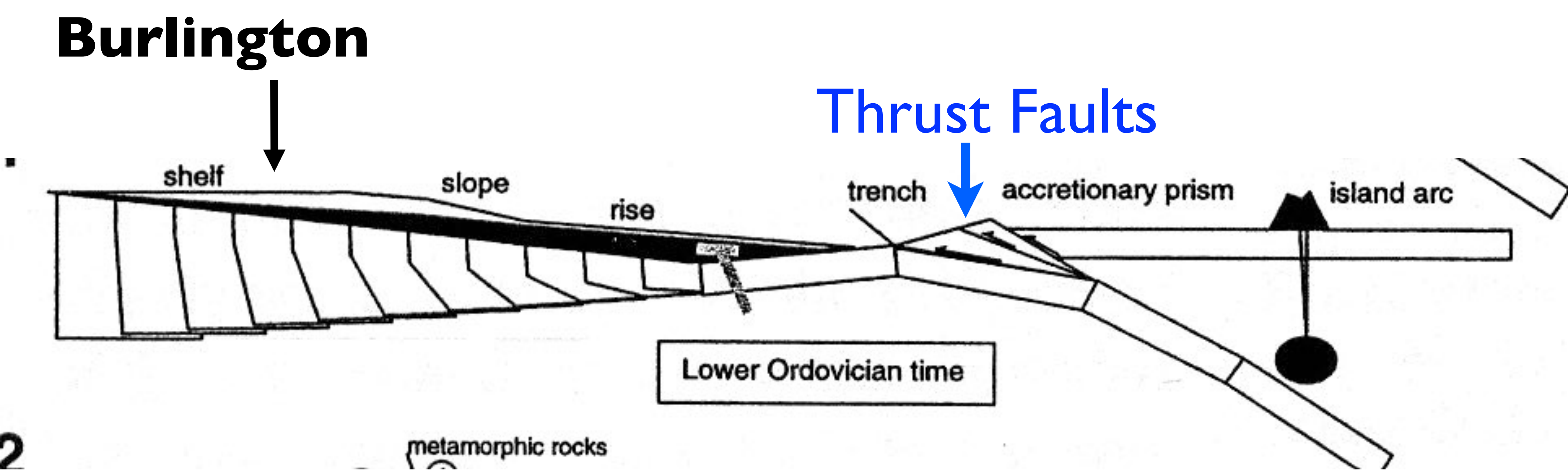
Cross-section showing Laurentia (North America) and the Iapetus Ocean subducting beneath a volcanic arc.



The mud that formed the Iberville shale you saw at Lone Rock Point was eroded from this volcanic arc.


Paleogeography of Laurentia during the early Ordovician time period (~480 million years ago).
This volcanic was moving towards Laurentia and eventually collided with it.
Laurentia (N. America)
Iapetus Ocean
Volcanic Arc
Oceanic Trench (subduction zone)

- As the volcanic arc moved closer to the edge of North America, oceanic lithosphere (part of the Iapetus Ocean was subducted.
- Sediment deposited on the deep sea floor was telescoped together along thrust faults where the plates converged, forming an "**<u>accretionary wedge,</u>**" a prism or wedge of accreted sediments scraped off the subducting lithosphere.



The collision of the volcanic arc and Laurentia produced the **Taconic Orogeny** **(~470–445 Ma)**.

This is the event that metamorphosed and deformed the rocks in the Green Mountains and caused the thrust faulting at Lone Rock Point.

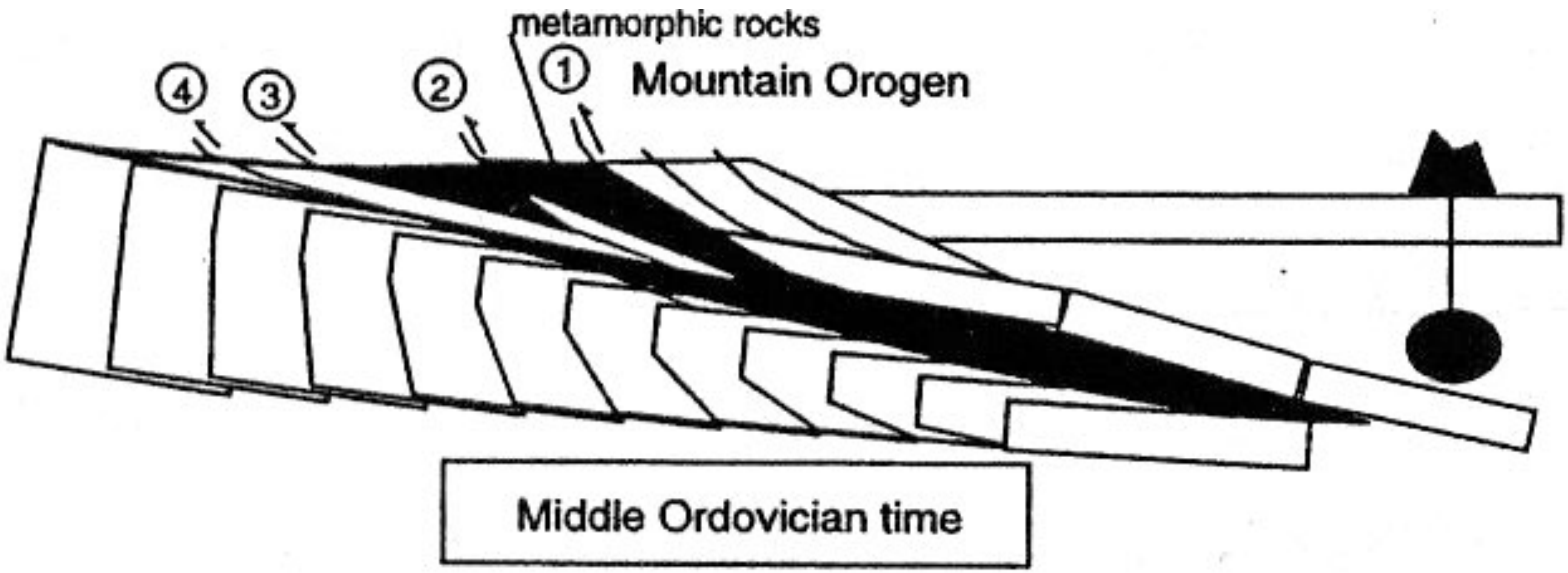


Figure by Barry Doolan

Orogenies

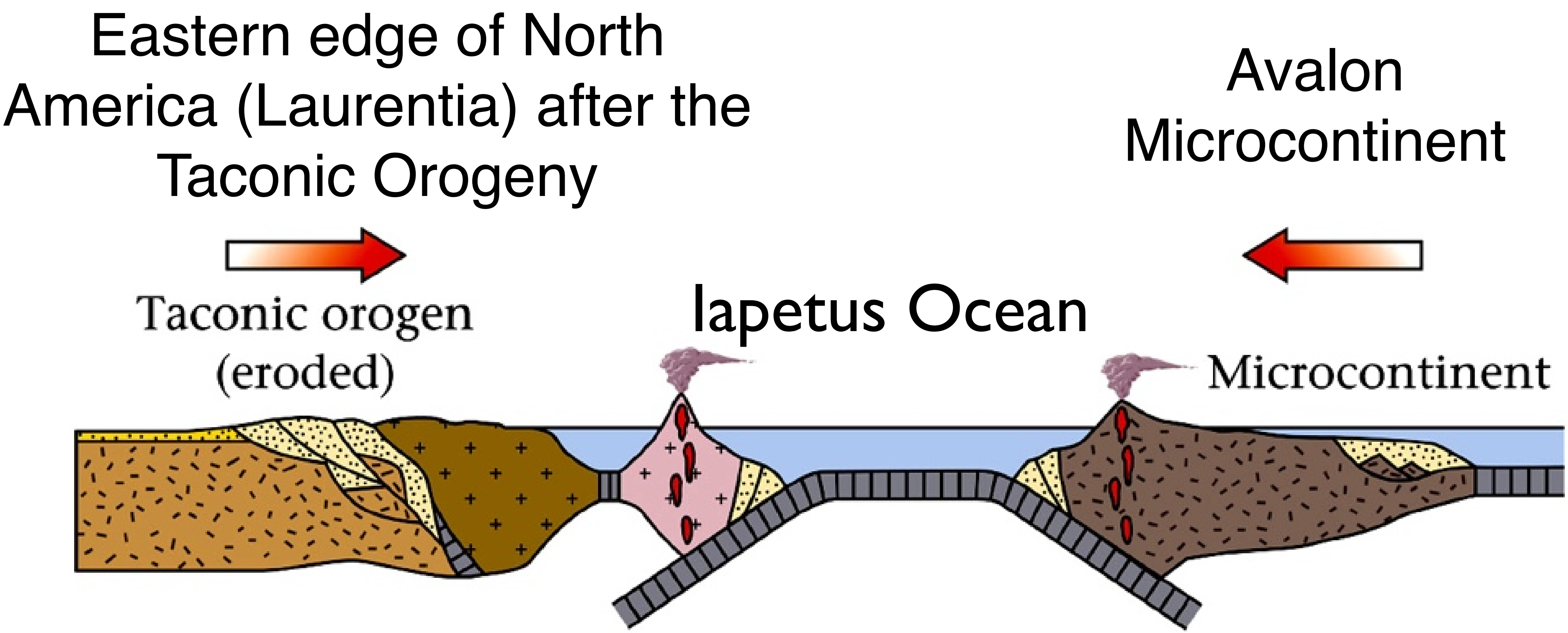
“Mountain Building Events”

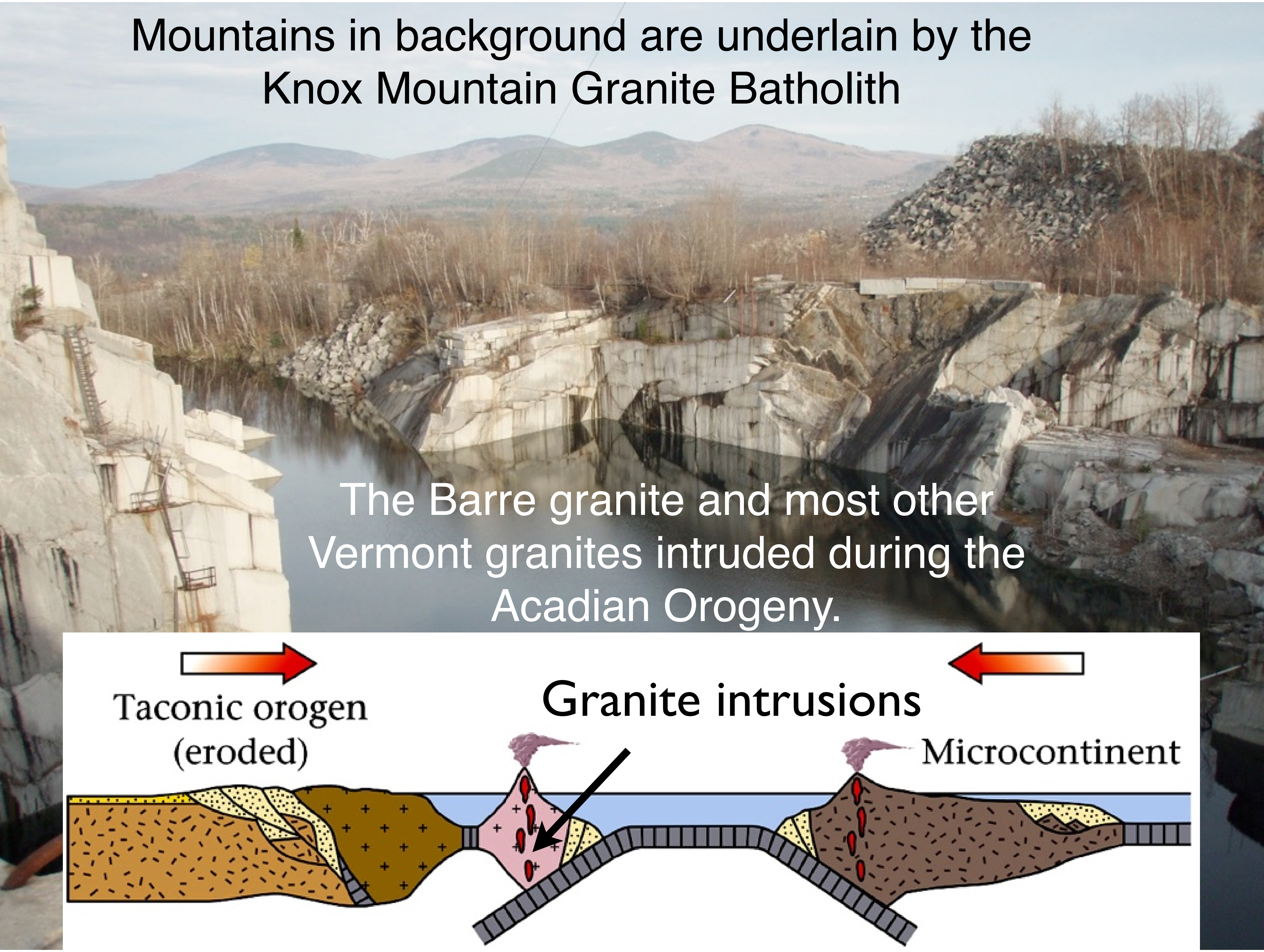
- **Orogeny** is a term used to describe all of the geological processes occurring during mountain building including:
  - Folding, faulting, earthquakes, metamorphism, generation of magma, intrusion of igneous rocks, extrusion of volcanic rocks
- An **Orogen** is another name for a mountain belt.

Map shows the **Taconic Orogen** (mountain belt formed during the **Taconic Orogeny**) and the distribution of the continents following the Taconic Orogeny.

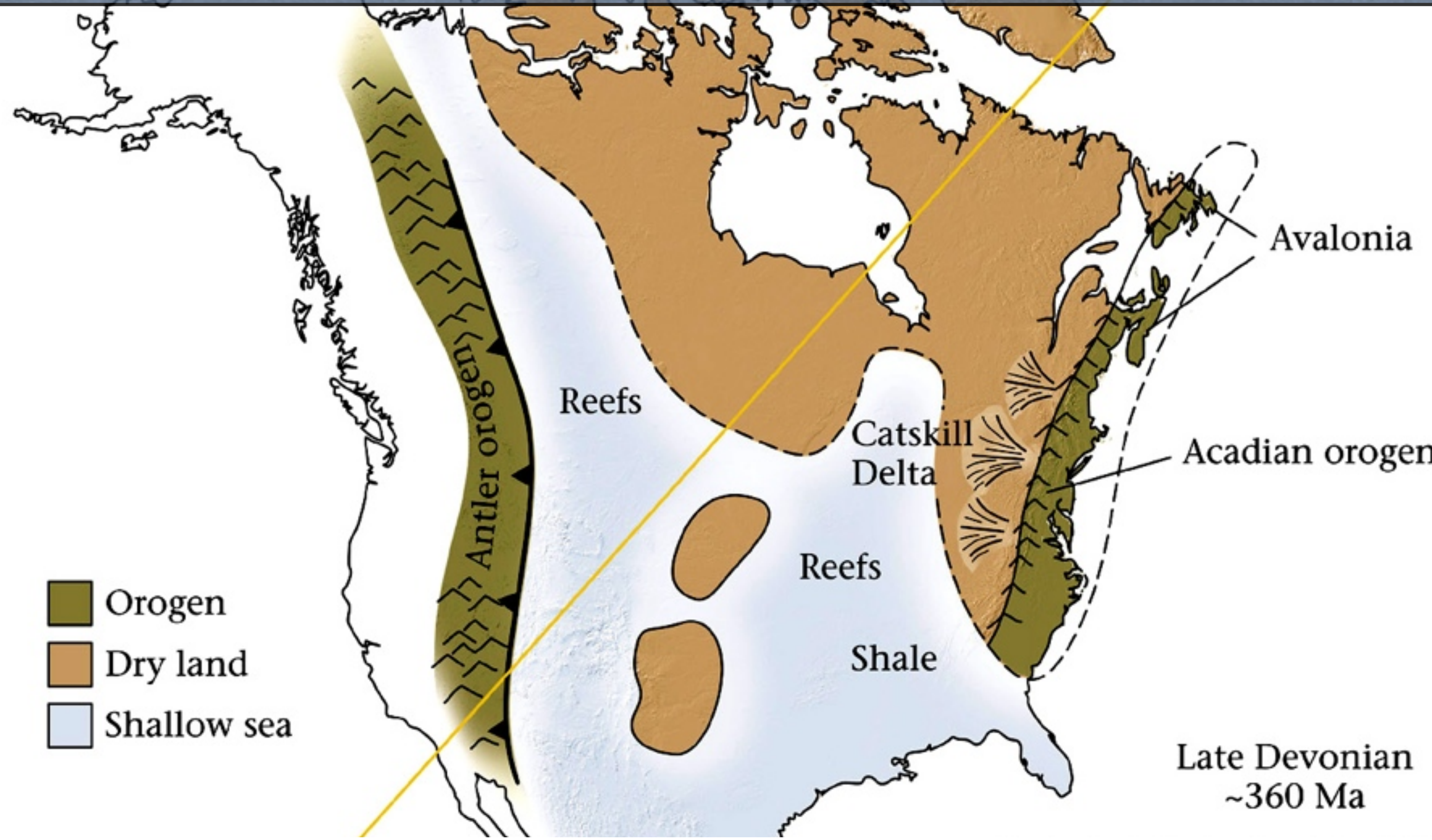
- Notice that the **Iapetus Ocean** hasn't disappeared. The Northfield slate and the Waits River formation were deposited in this part of the Iapetus Ocean.
- Also notice that another continent named **Avalon** is moving towards North America.

- The collision of Avalon with North America produced the **Acadian Orogeny**.
- If you are from New Hampshire, coastal Maine, eastern Massachusetts, eastern Connecticut, or Rhode Island, you are living on Avalon!



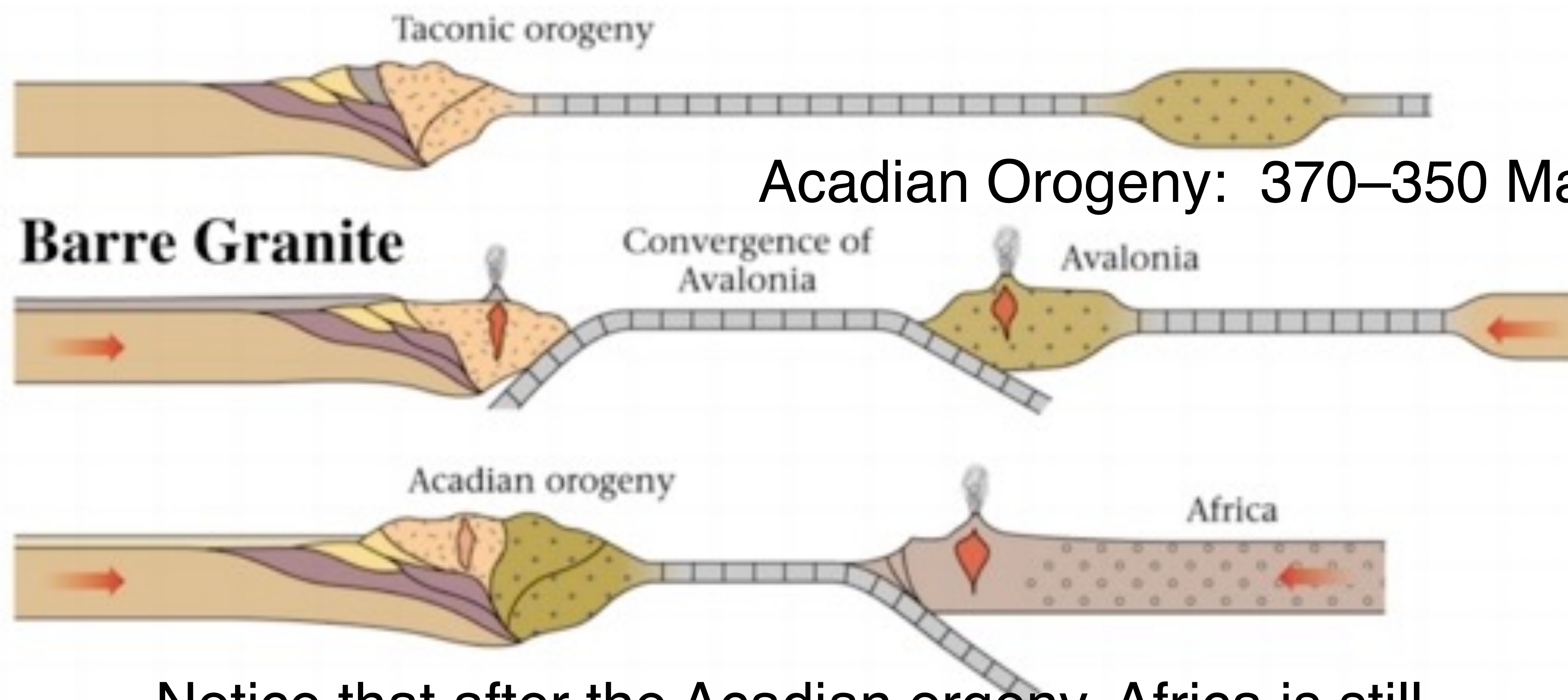

Mountains in background are underlain by the Knox Mountain Granite Batholith
The Barre granite and most other Vermont granites intruded during the Acadian Orogeny.
Taconic orogen (eroded)
Granite intrusions
Microcontinent

The mountains produced by the Acadian Orogeny were extensive. As they eroded they shed sediment over a broad area. The Catskill Mountains and many parts of western NY and PA are composed almost entirely of sedimentary rock derived from the erosion of the Acadian Mountains.



Taconic Orogeny: 470–445 Ma

Acadian Orogeny: 370–350 Ma



Notice that after the Acadian orgeny, Africa is still approaching North America:
There's one more orogeny that affected the Appalachian Mountains: The Alleghenian Orogeny!

The Alleghenian Orogeny resulted from the collision of Africa with North America. This is the final event that produced the supercontinent of **Pangaea**.