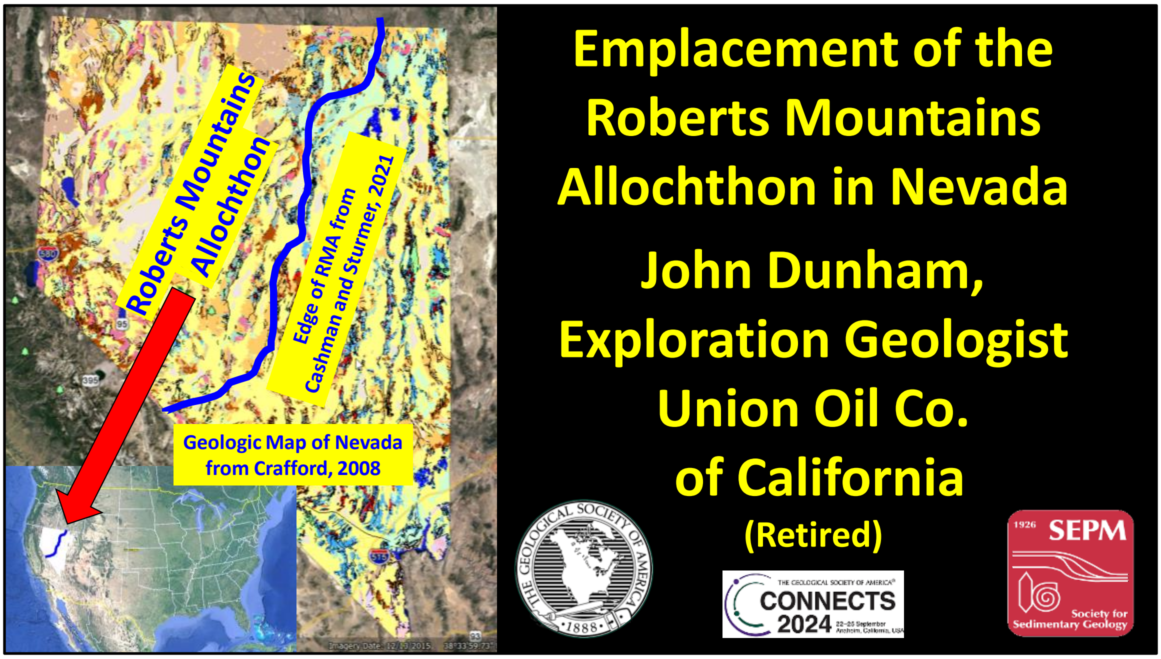

Emplacement of the Roberts Mountains Allochthon in Nevada

John Dunham, Exploration Geologist Union Oil Co. of California (Retired)

THE GEOLOGICAL SOCIETY OF AMERICA
CONNECTS 2024
22–25 September
Anaheim, California, USA

1926 SEPM
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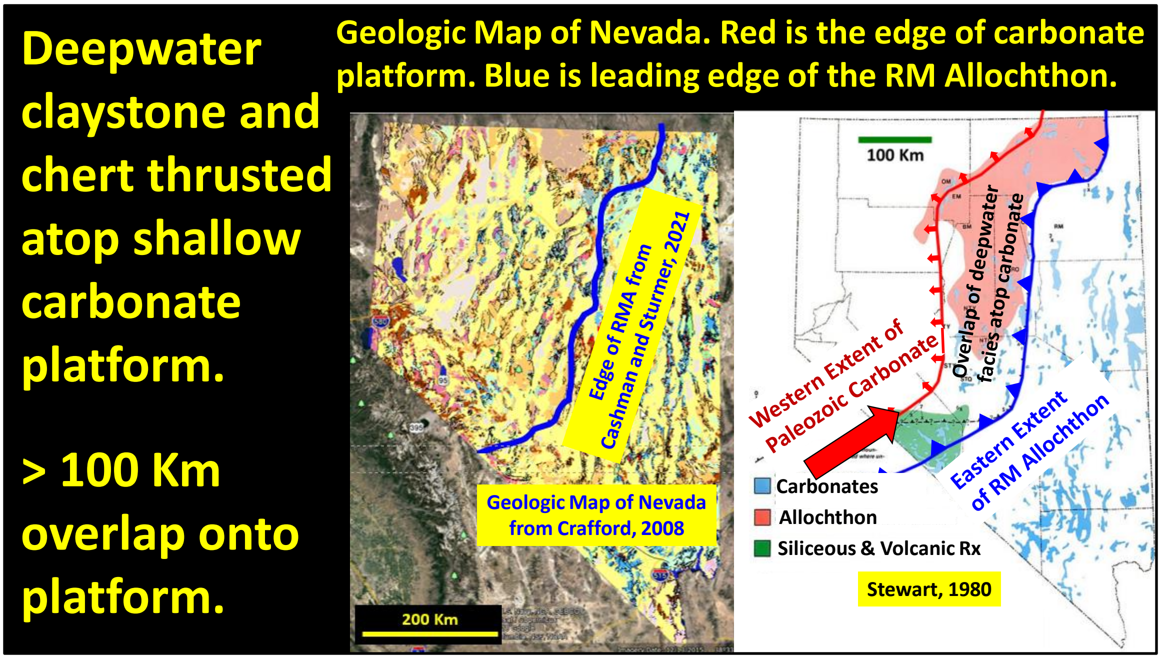
As a grad student 50 years ago, I mapped and measured sections in the Roberts Mountains and other ranges in Central Nevada, focusing on the lower Paleozoic carbonate platform. The allochthon above the platform was an enigma.

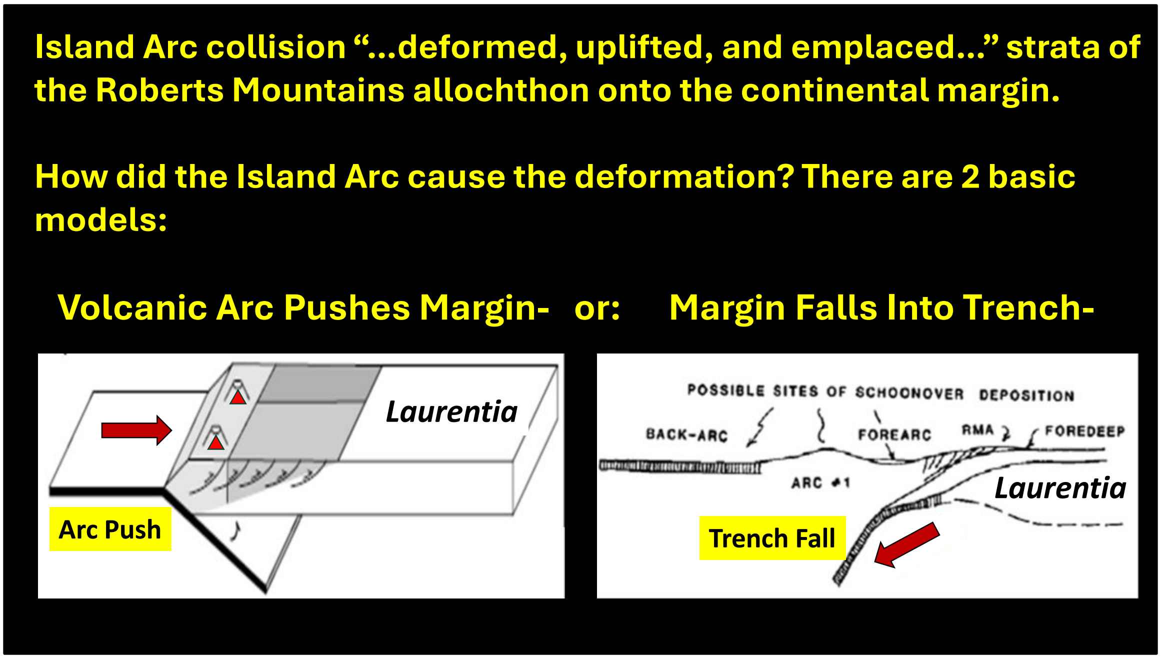


Deepwater claystone and chert thrusted atop shallow carbonate platform.

> 100 Km overlap onto platform.

Geologic Map of Nevada. Red is the edge of carbonate platform. Blue is leading edge of the RM Allochthon.

There were multiple theories, but a common element was that "…deep water sedimentary rocks were uplifted and transported eastward on the order of 150 km, onto the carbonate platform of western Laurentia." How did this happen?

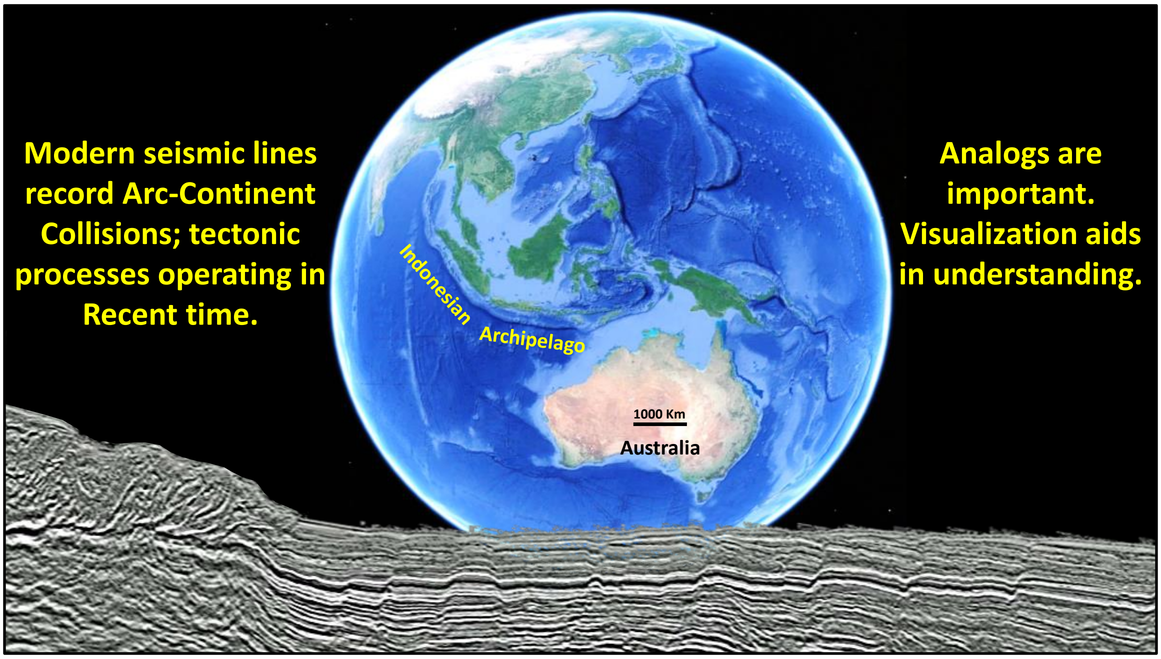


Island Arc collision "…deformed, uplifted, and emplaced…" strata of the Roberts Mountains allochthon onto the continental margin.

How did the Island Arc cause the deformation? There are 2 basic models:

Volcanic Arc Pushes Margin- or: Margin Falls Into Trench-

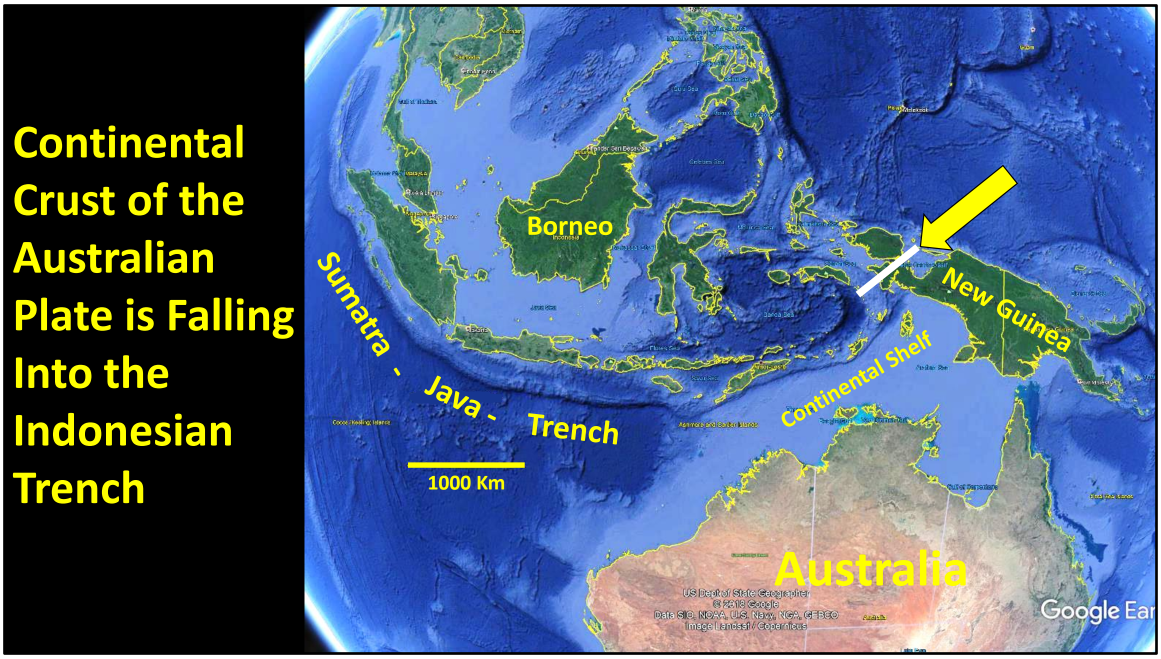
Island Arc collision was used to explain obduction of the allochthon; but there were two basic models. Either, a volcanic arc pushed against the margin; or, the continental margin fell into a subduction trench.



Modern seismic lines record Arc-Continent Collisions; tectonic processes operating in Recent time.

Analogs are important. Visualization aids in understanding.

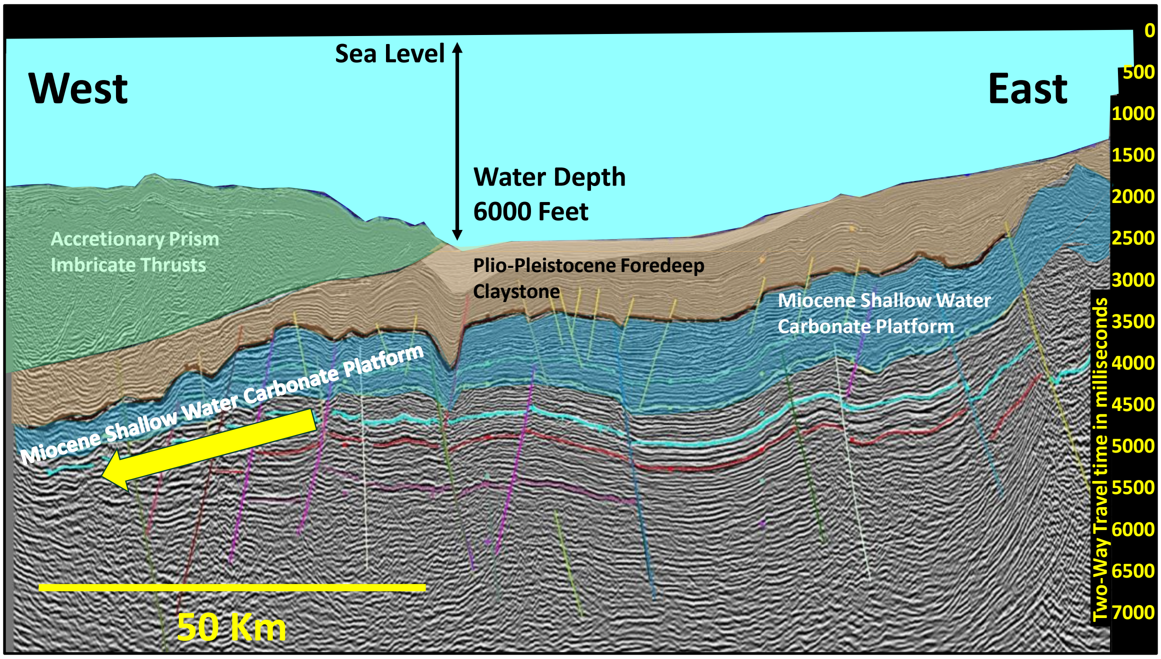
After school, I moved on to Industry where I worked on exploration projects in Trinidad, Venezuela, and Indonesia, with seismic lines that reminded me of Nevada.



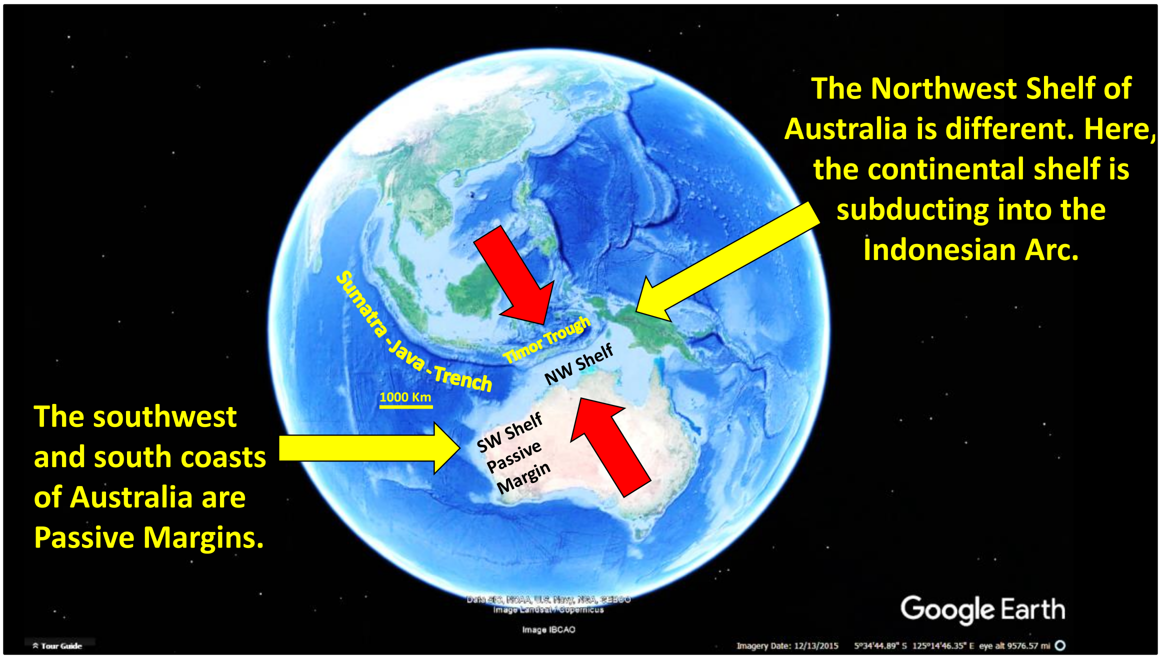
Continental Crust of the Australian Plate is Falling Into the Indonesian Trench

US Dept of State Geographer
© 2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

Here, I was looking at the Western tip of New Guinea, where continental crust of the Australian plate is falling into the Eastern Indonesian subduction zone.



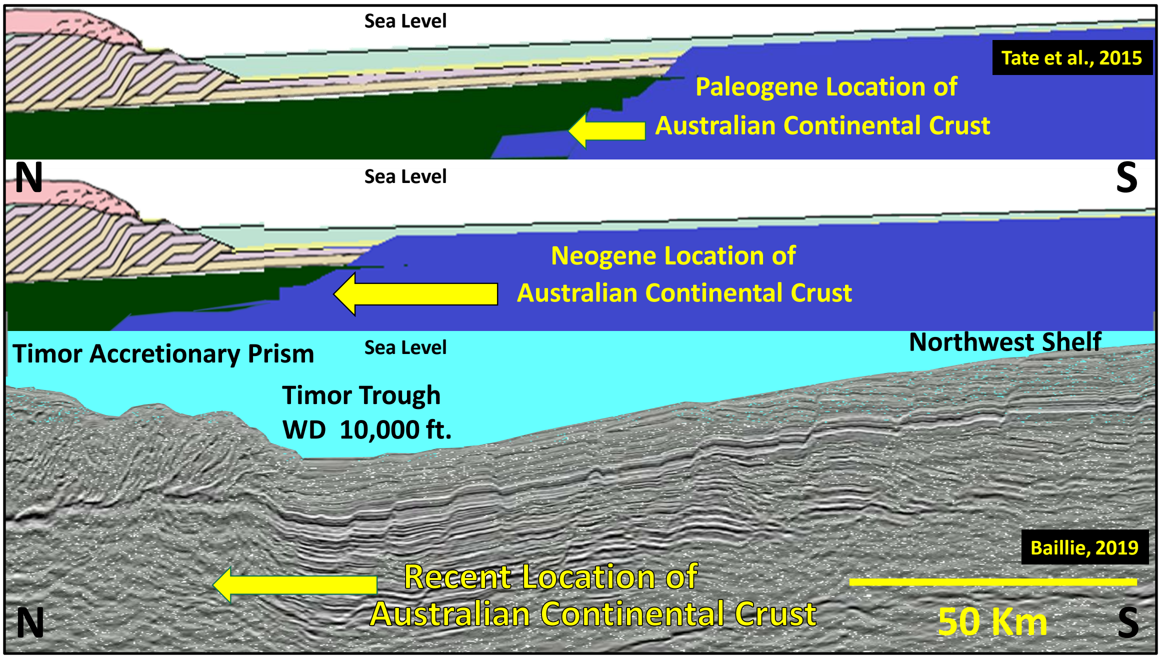
A Miocene shallow-water carbonate platform is falling into a subduction trench. A detachment surface separates the subducting lower plate from an overlying accretionary prism of sediment scraped off the descending plate. The Miocene carbonates accumulated in shallow water. However, as subsidence accelerated due to descent into the trench, the carbonate platform stopped growing due to drowning and was overlain by deep-water Plio-Pleistocene mudstone.



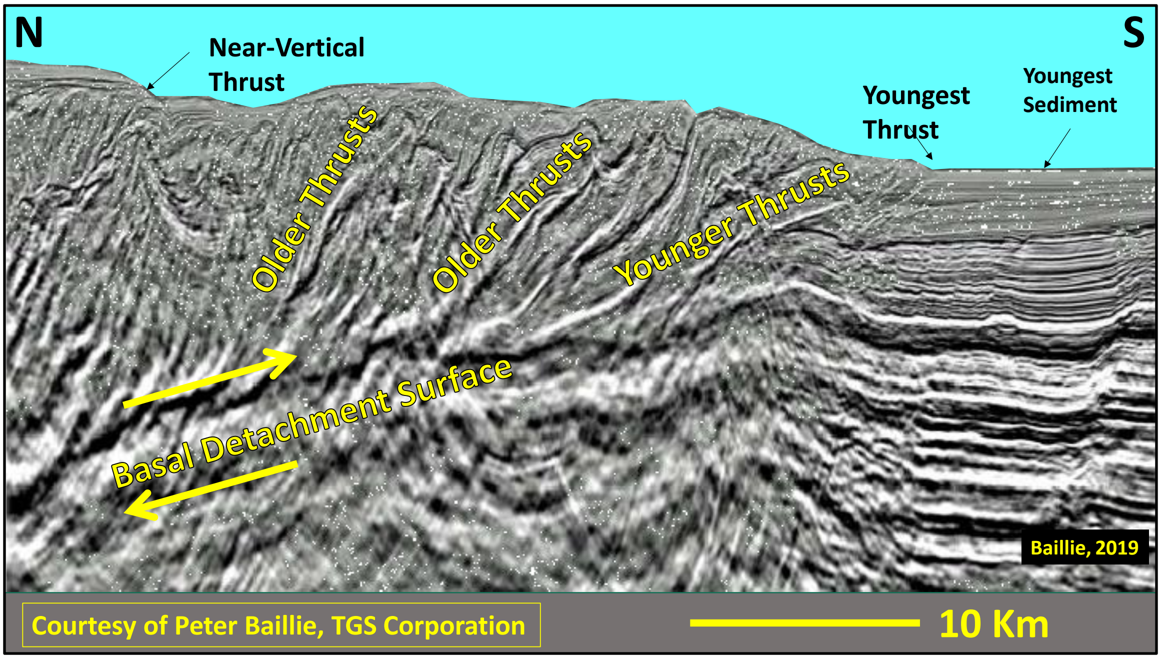
The Northwest Shelf of Australia is different. Here, the continental shelf is subducting into the Indonesian Arc.

The southwest and south coasts of Australia are Passive Margins.

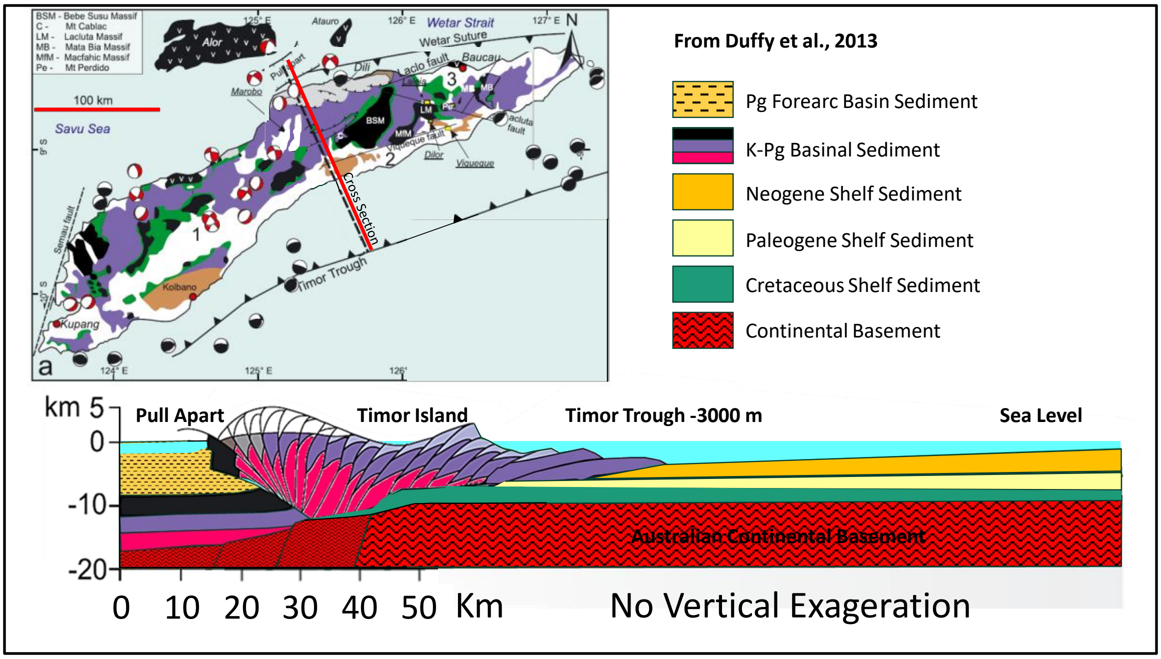
The northwest shelf of Australia has collided with the East Indonesia subduction zone. Australia rifted from Gondwanaland in Jurassic time and has migrated north ever since. At the same time, the Indonesian subduction zone is moving south through the process of slab rollback. Simply by coincidence, these plates have encountered one another. Note that Australia’s south and southwestern coasts remain passive margins. Only the Northwest Shelf has collided with the Timor Trough.



Continental Crust of the Australian Northwest Shelf is falling into the Timor Trough. Deepwater sediment scrapes off the descending plate and piles up into an accretionary prism.

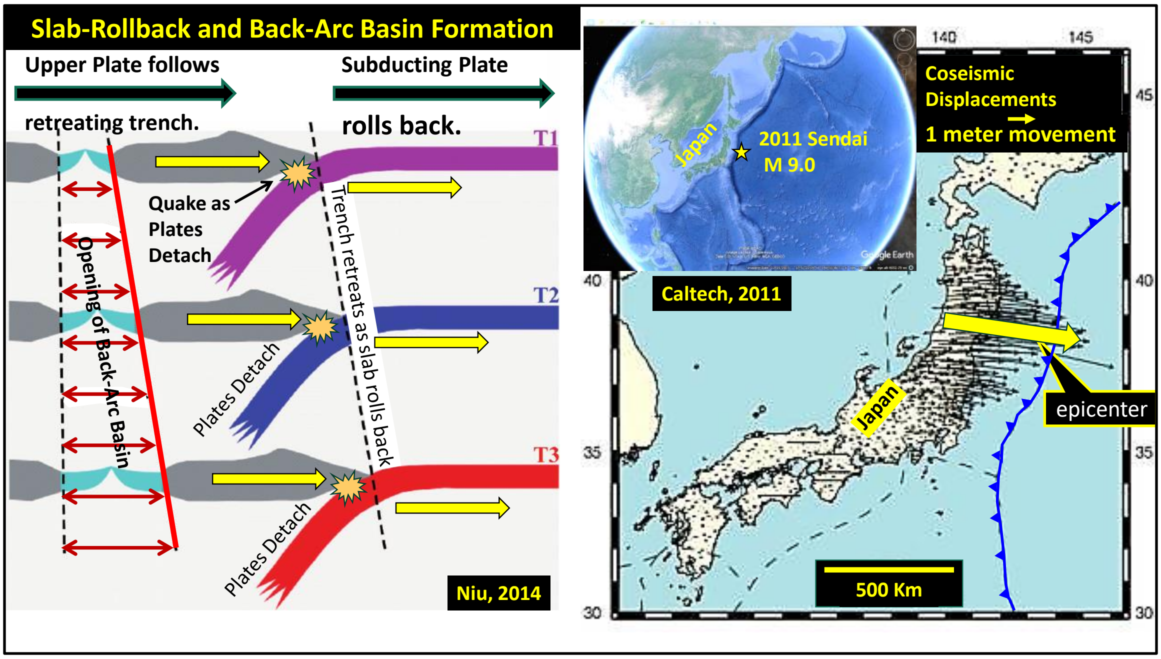


The Timor Accretionary Prism shows a classic sequence of forward-breaking thrusts. The youngest thrust cuts the sea floor at the edge of the trench. Each young thrust uplifts all the older thrusts behind it. The youngest thrust cuts the youngest sediment at the bottom of the trench, while older slices stack into the higher parts of the prism.



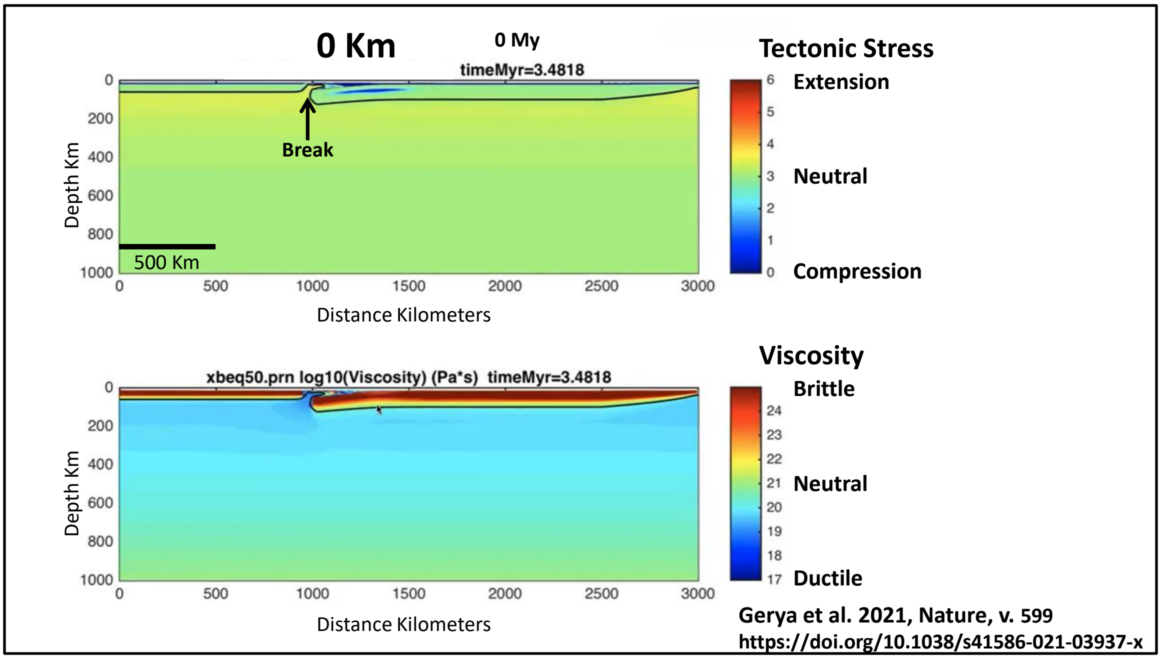
From Duffy et al., 2013

What happens when each young thrust uplifts the older thrusts behind it? The imbricates rotate to vertical positions and eventually overturn and deform sediments in pull-apart basins in front of the volcanic arc.



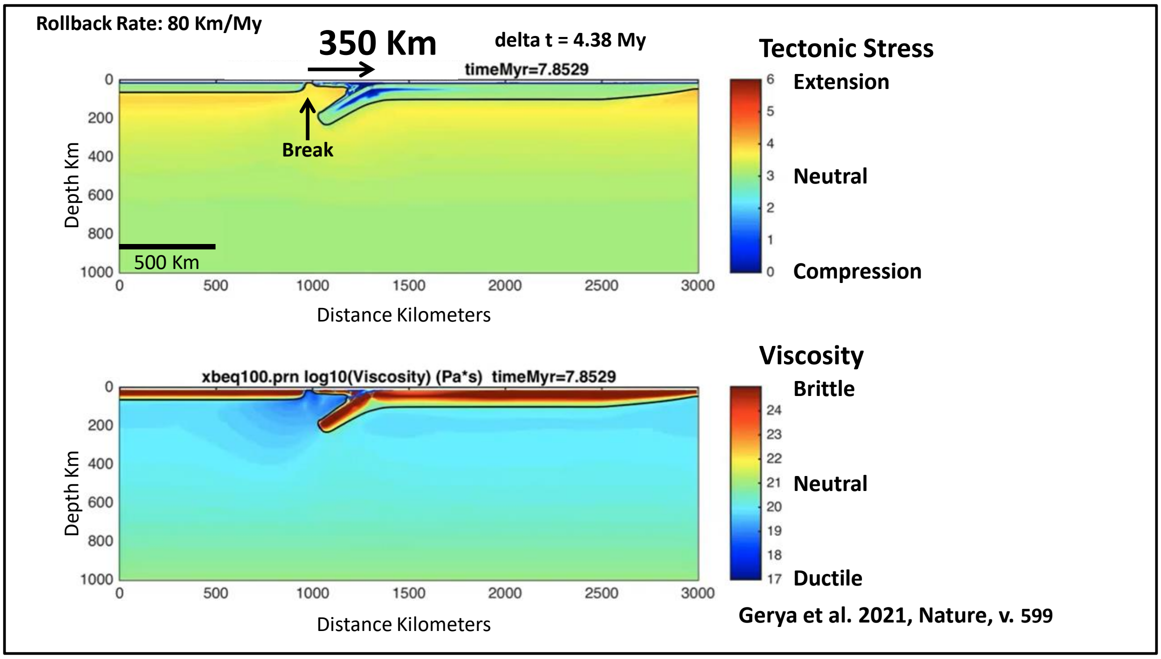
Slab-Rollback and Back-Arc Basin Formation

Slab Rollback drives migration of oceanic trenches. Over time, the hinge of the subducting plate rolls back away from the trench. The Japan map shows GPS ground motion following the magnitude 9 Sendai Earthquake when the upper and lower plates of the subduction zone detached. The hinge line of the descending slab moved east, and at the same time, the upper plate instantaneously moved east up to 10 meters to take up space left behind by the retreating lower plate.



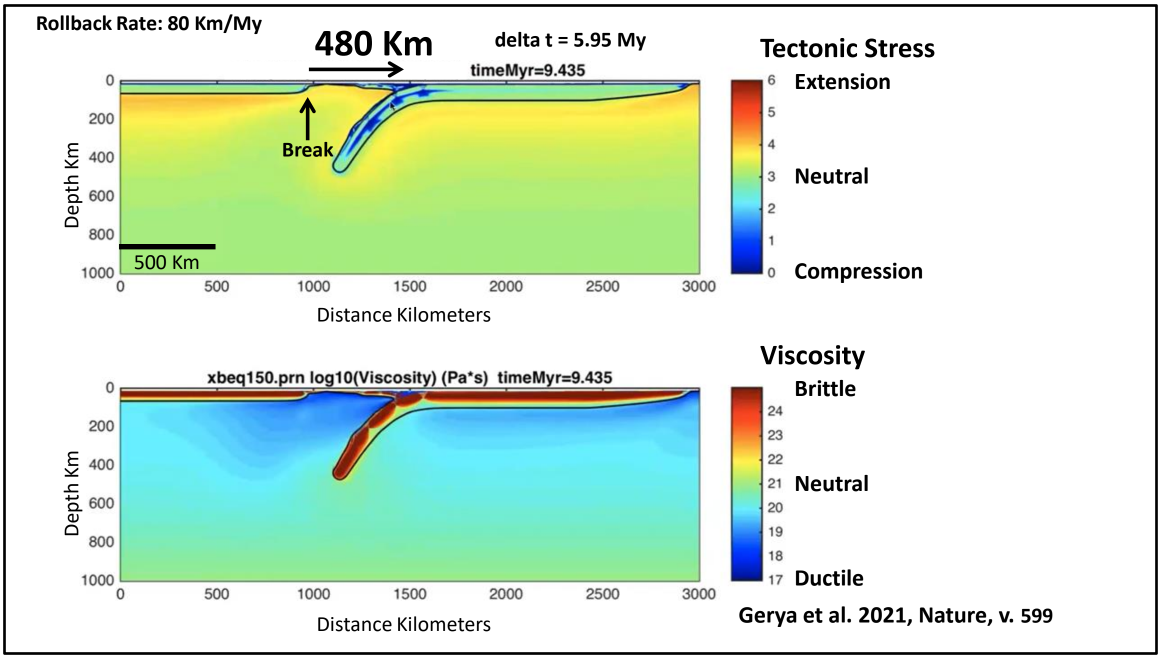
Gerya et al. 2021, Nature, v. 599
https://doi.org/10.1038/s41586-021-03937-x

Gerya generated a numeric model for the subduction of oceanic lithosphere. A cold, dense slab is negatively buoyant as it floats on the Asthenosphere. If anything causes a break in the slab, one edge of the break will begin to subside.



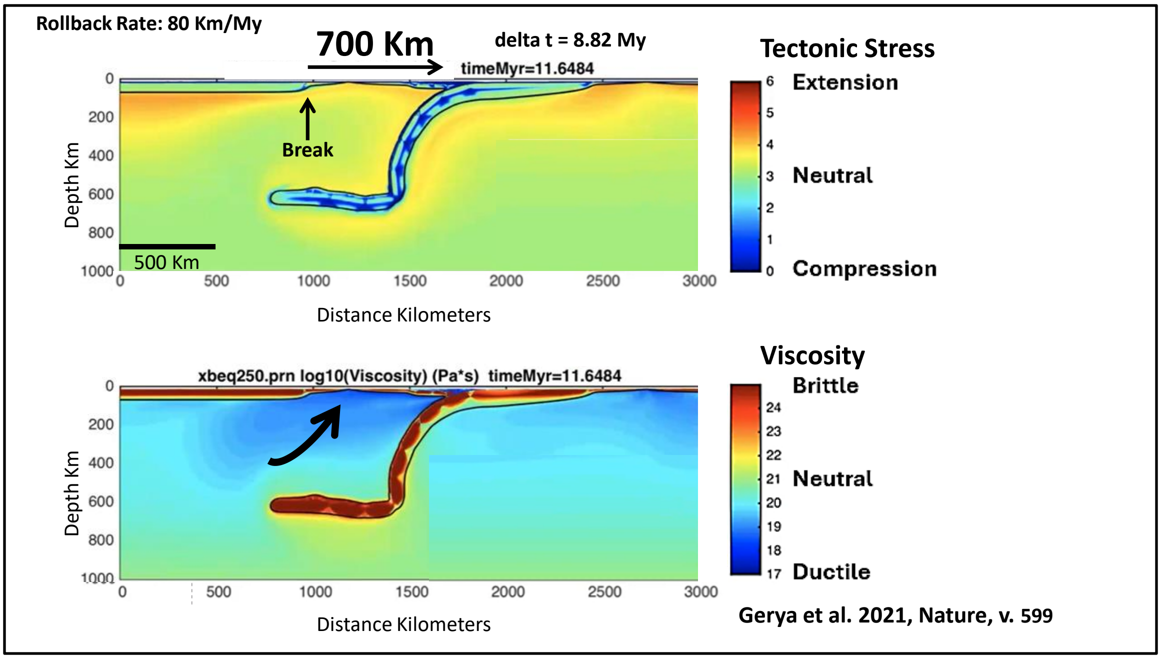
Gerya et al. 2021, Nature, v. 599

The subsiding plate flexes along a hinge line that moves back away from the break.



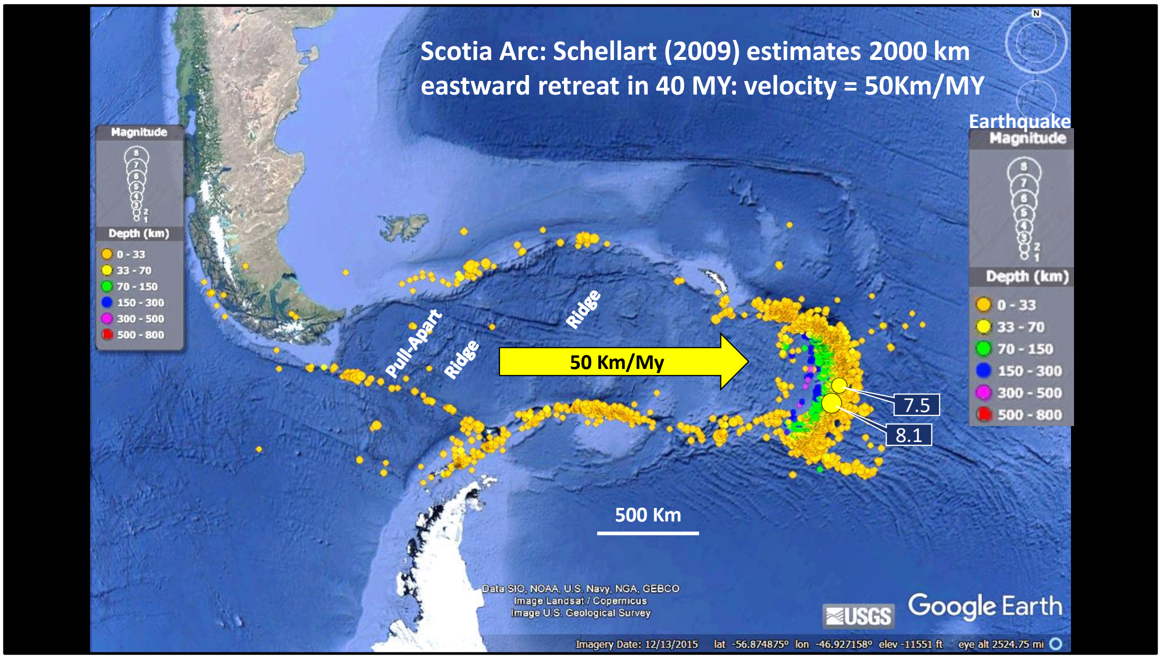
Gerya et al. 2021, Nature, v. 599

The subsiding plate continues to bend and roll back.



Gerya et al. 2021, Nature, v. 599

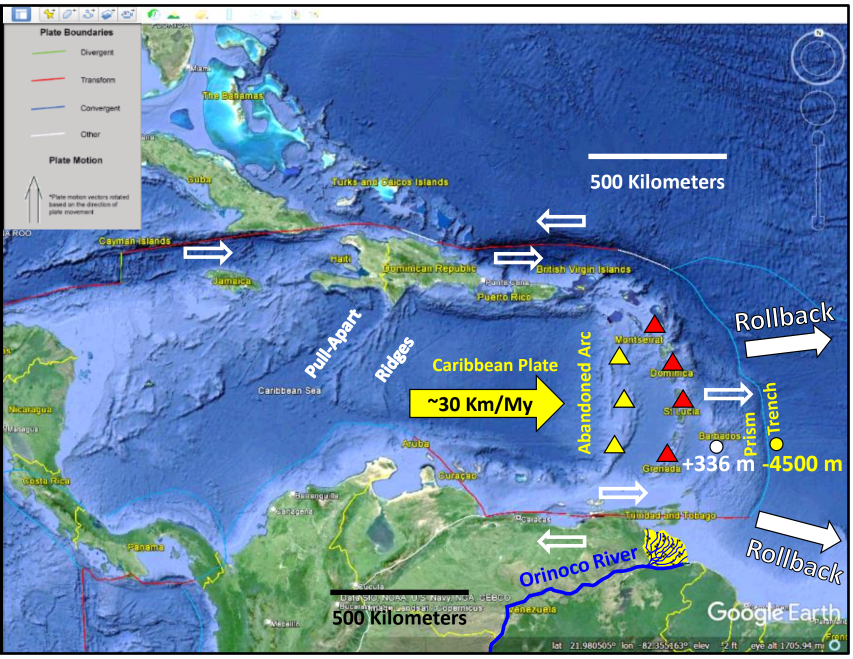
Eventually, the subducting slab has migrated hundreds to thousands of kilometers from the original break. Note how hot ductile asthenosphere rises into back-arc pull-apart ridges.



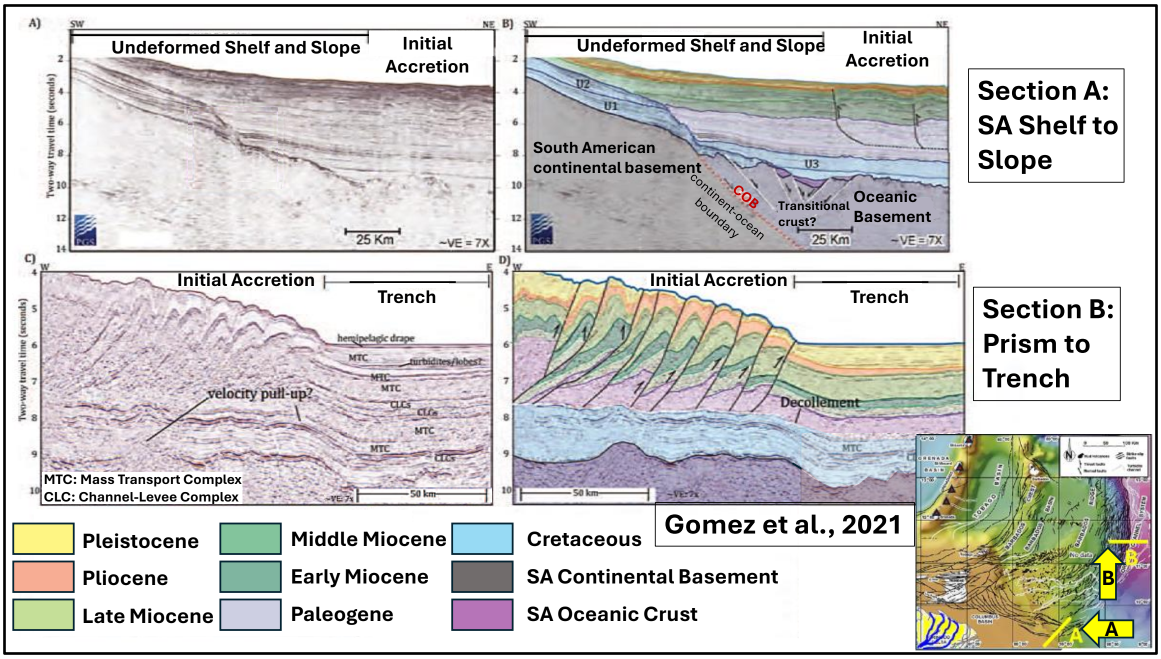
Scotia Arc: Schellart (2009) estimates 2000 km eastward retreat in 40 MY: velocity = 50Km/MY

Oceanic trenches actively migrate across plates of ocean crust at plate tectonic rates. Estimates from the Scotia Arc indicate 50 km of migration per million years.

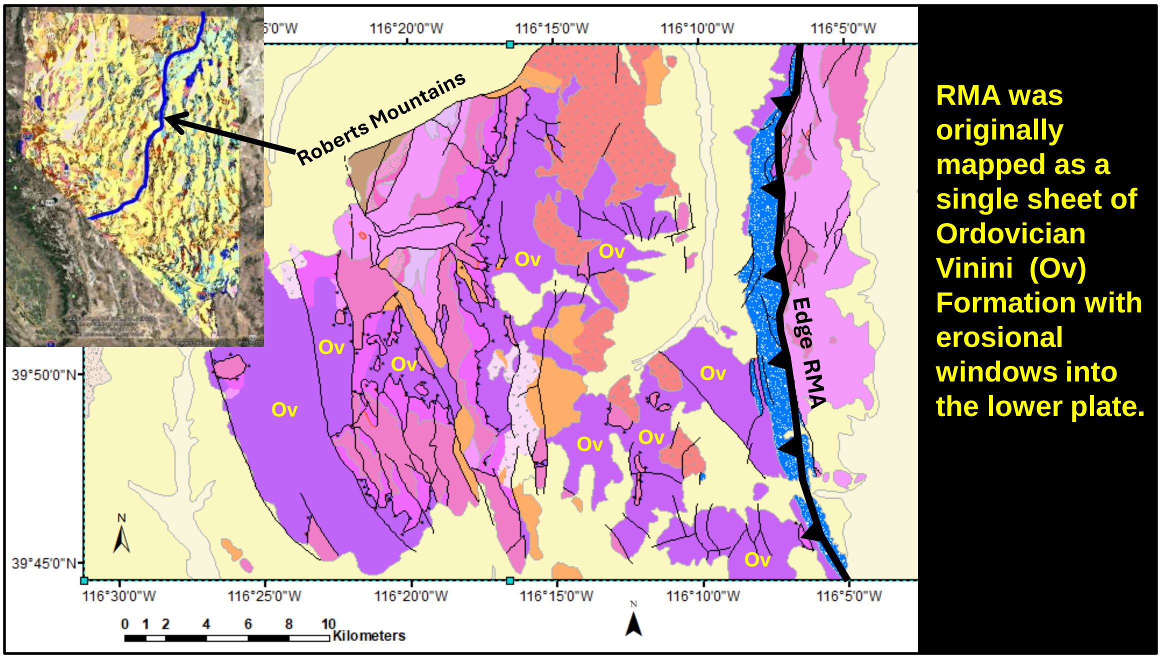
Oblique Collision of South American Plate and Caribbean Plate driven by slab-rollback at the Lesser Antillies Trench.



The Caribbean Plate is an example of an oblique collision with a Continental Margin. The elevation between the top of the Barbados Accretionary Prism and the bottom of the Antilles Trench is over 4500 meters.



An extensive seismic grid covers the Barbados Accretionary Prism. Section A shows South American continental crust beginning its descent into the trench. Section B is perpendicular to the trench and shows the youngest imbricates at the leading edge of the prism.



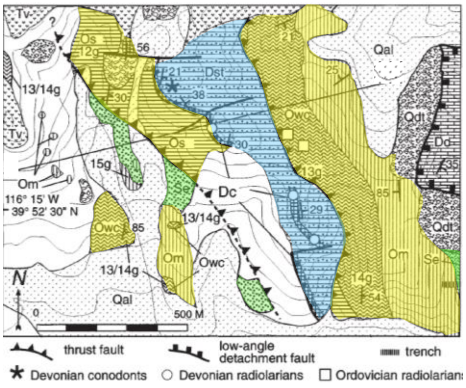
RMA was originally mapped as a single sheet of Ordovician Vinini (Ov) Formation with erosional windows into the lower plate.

Work in Indonesia and the Caribbean brought to mind what I'd seen in the Roberts Mountains. Shelf-edge carbonate platform sediments are overlain by deepwater graptolitic shales mapped initially as a single sheet of Ordovician Vinini Formation.

Recognition of fine-scale imbricate thrusts in lower Paleozoic orogenic belts—An example from the Roberts Mountains allochthon, Nevada

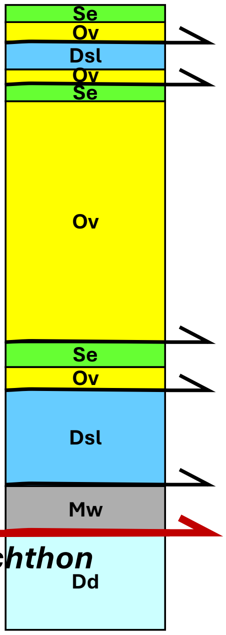
Geology; **June 1999; v. 27; no. 6; p. 543–546**

P.J. Noble Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno
S.C. Finney Department of Geological Sciences, California State University, Long Beach, CA



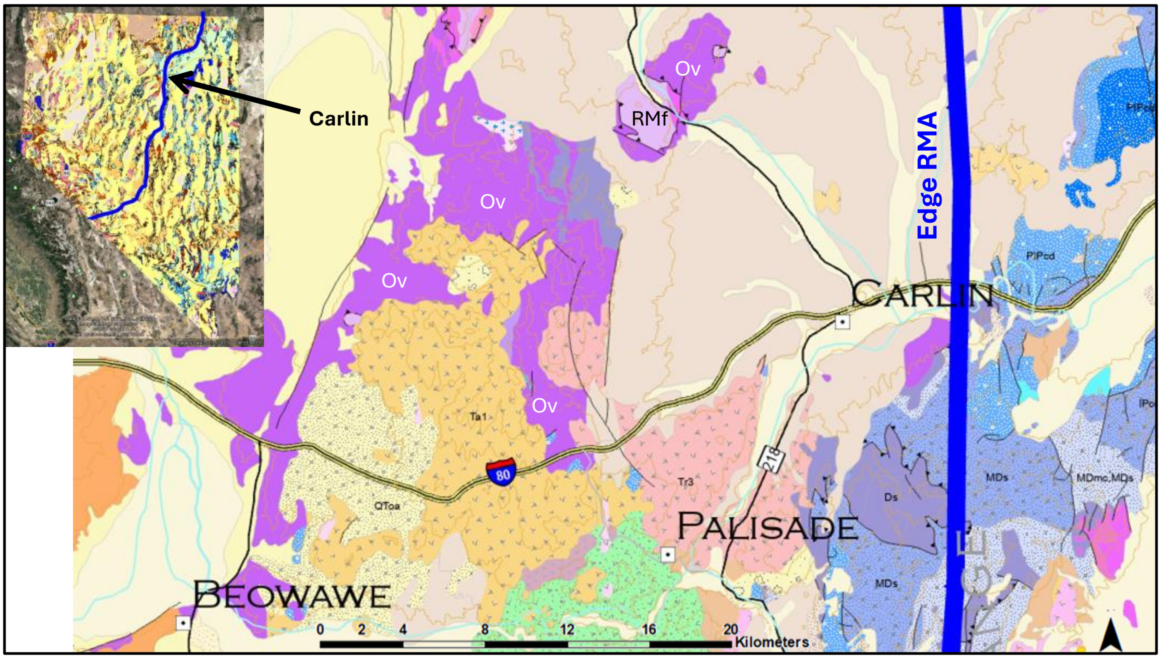
Mw	**Mississippian Web Fm.** Shale, siliceous mudstone, and thin chert layers
Dsl	**Devonian Slaven Fm.** Radiolarian Chert with thin shale and carbonate
Se	**Silurian Elder Fm.** Fine quartz sand to silt with thin chert layers
Ov	**Ordovician Vinini Fm.** Graptolite shale, thin chert, carbonate turbidites
Dd	**Devonian Devil's Gate Fm.** Fossiliferous Platform Limestone

R.M. Allochthon

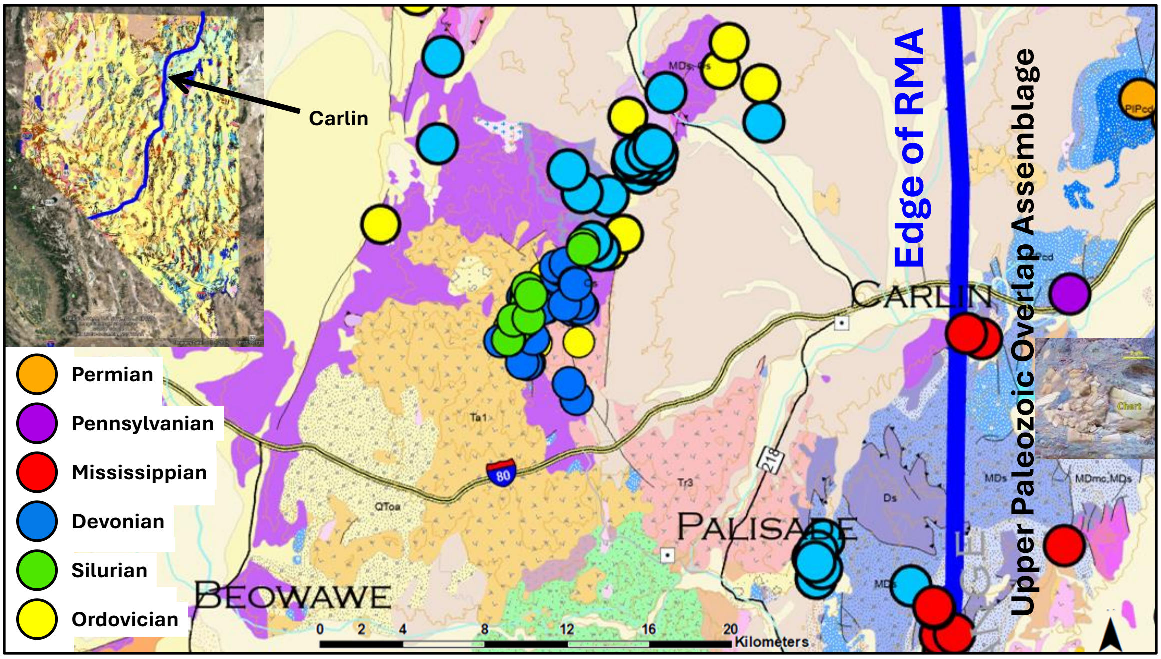


Autochthon

Advances in biostratigraphy by Professors Noble and Finney led to identification of Silurian and Devonian thrust slices within the allochthon.



Farther North in the Carlin Area the allochthon was also mapped as a single sheet of Vinini Formation.

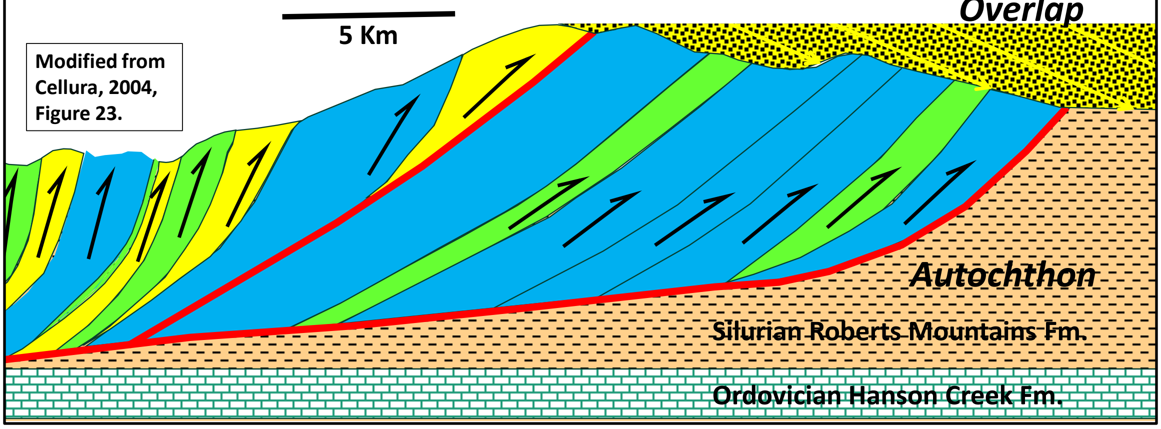


Brian Cellura applied Noble and Finney's methods to recover microfossils that assigned Ordovician, Silurian, and Devonian ages to the imbricates of the Roberts Mountains Allochthon, overlapped by undeformed Upper Paleozoic sands and gravels.

Older Sediments and Faults to the West;
Younger Sediments and Faults to the East.

Allochthon

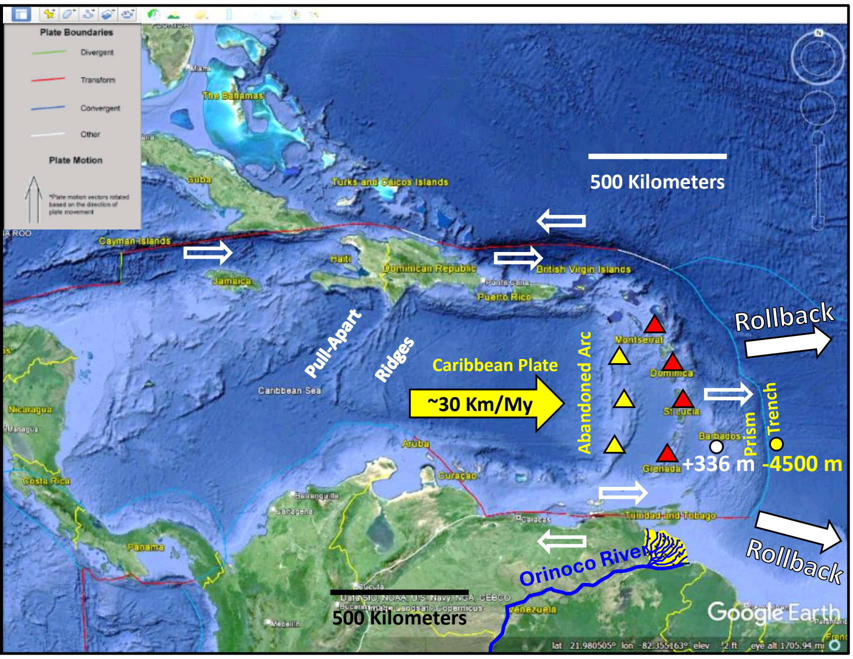
Ov	**Ordovician Vinini Fm.** Graptolite shale, thin chert, carbonate turbidites	Se	**Silurian Elder Fm.** Fine quartz sand to silt with thin chert layers	Dsl	**Devonian Slaven Fm.** Radiolarian Chert with thin shale and carbonate



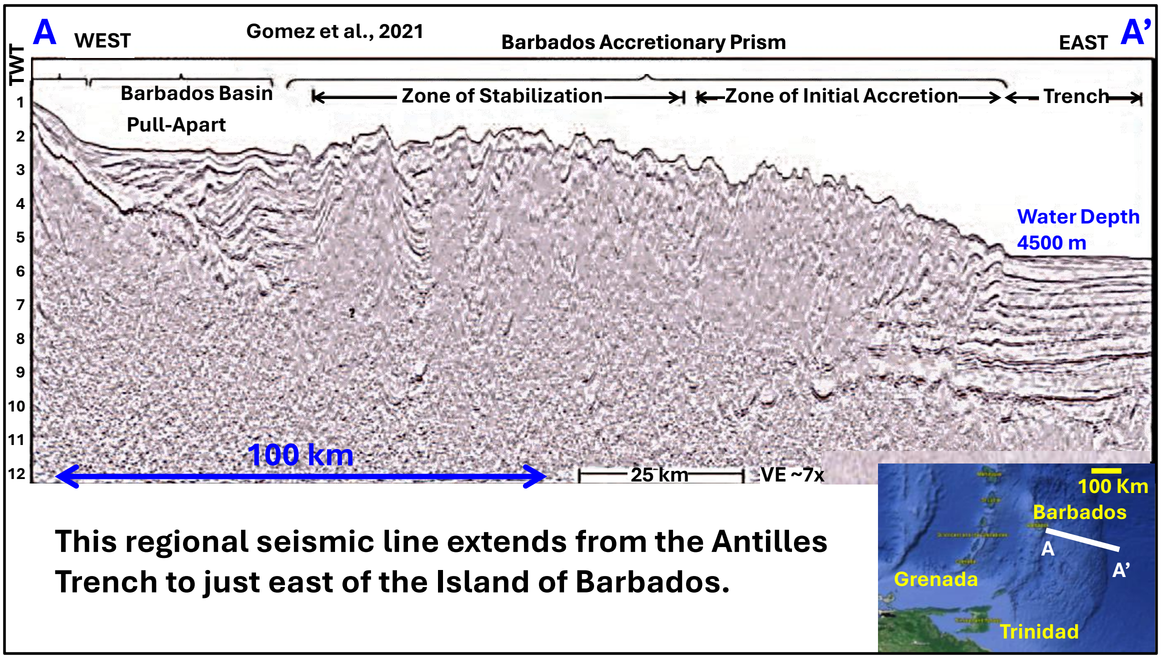
Modified from Cellura, 2004, Figure 23.

Cellura mapped imbricate thrusts near the Carlin Gold Mine. Using biostratigraphy, he correlated allochthon units from Carlin to the Roberts Mountains. Regionally extensive stratigraphy supported the view that the sediments at the leading edge of the allochthon came from the continental slope in front of the Lower Paleozoic carbonate shelf edge.

Oblique Collision of South American Plate and Caribbean Plate driven by slab-rollback at the Lesser Antillies Trench.

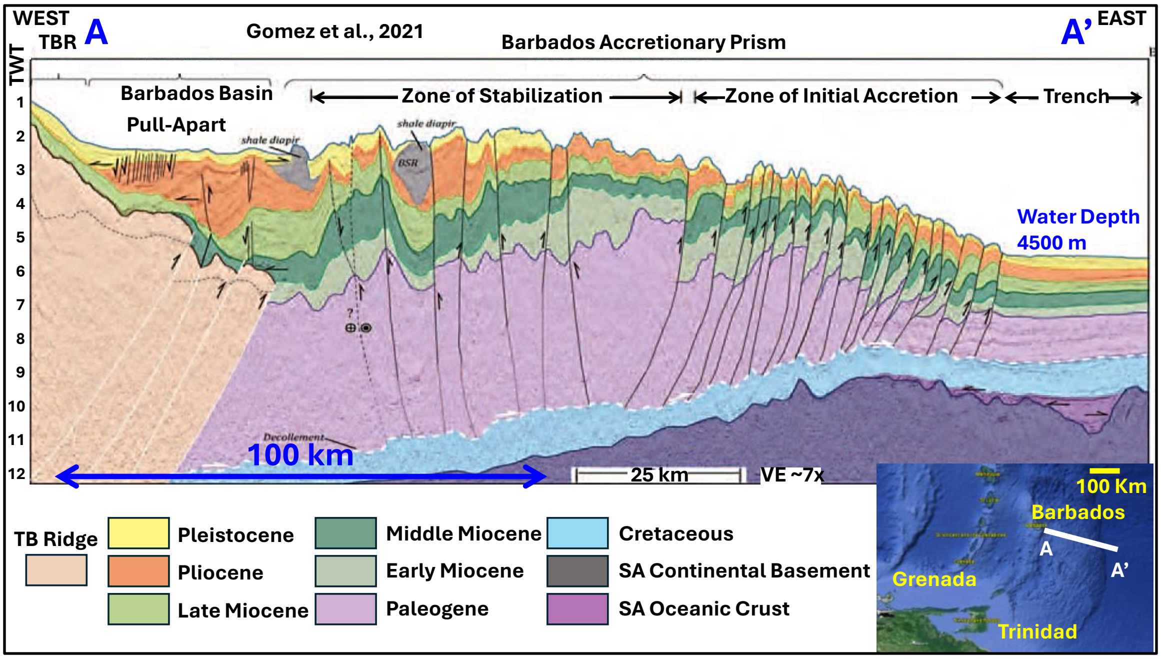


We’ll return to the Caribbean plate for comparisons to the Roberts Mountains allochthon.

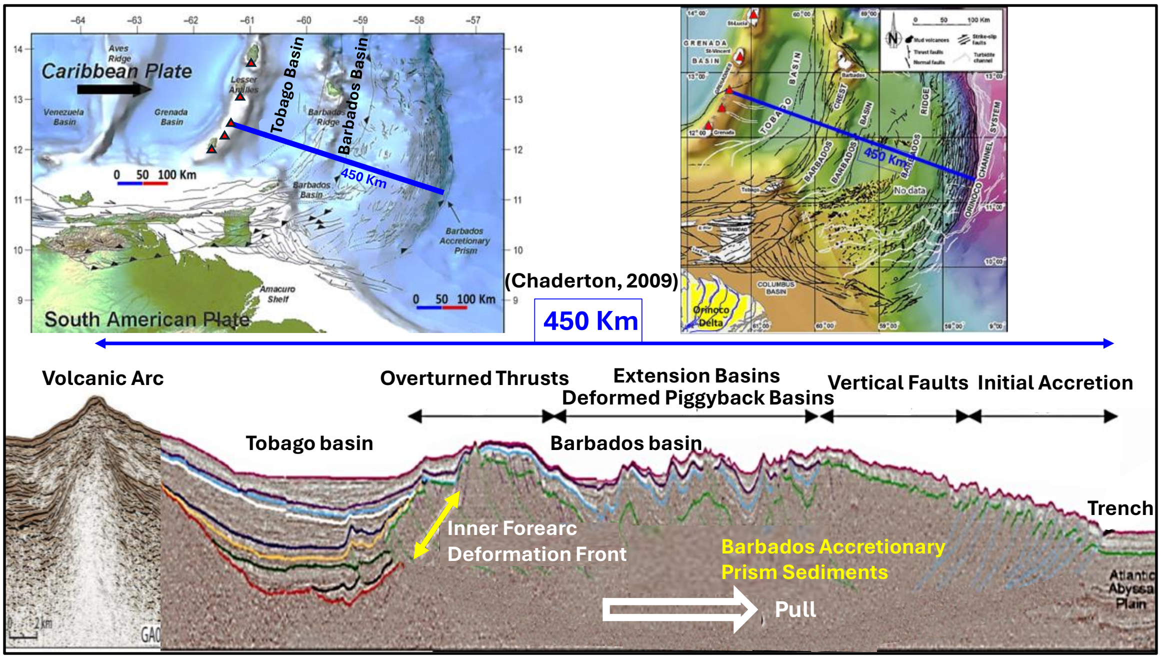


This regional seismic line extends from the Antilles Trench to just east of the Island of Barbados.

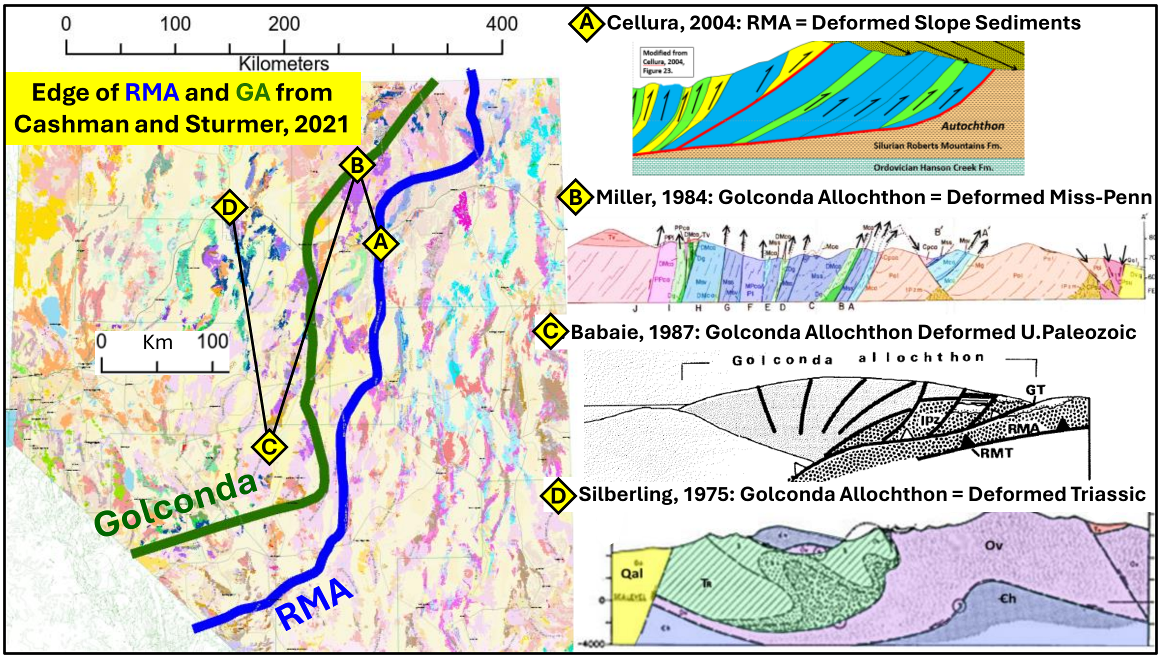
This regional seismic line extends from the Antilles Trench to just east of the Island of Barbados.



The Barbados Accretionary Prism divides into distinct structural zones. The trench contains undeformed sediment at the edge of the prism. The initial-accretion zone is a system of forward-breaking thrusts. In the stabilization zone, thrusts rotate into vertical positions and begin to overturn to the west. The zone of pull-apart basins is a region of tension created by eastward lurching of the upper plate as the lower plate retreats to the east through slab rollback.



Large pull-apart basins form at the trailing edge of the migrating prism. Continued uplift of young imbricates in the Accretion Zone rotates older thrusts that push against and deform sediments in the pull-apart basins. A volcanic arc lies over 400 km west of the trench front.



Edge of RMA and GA from Cashman and Sturmer, 2021

A Cellura, 2004: RMA = Deformed Slope Sediments

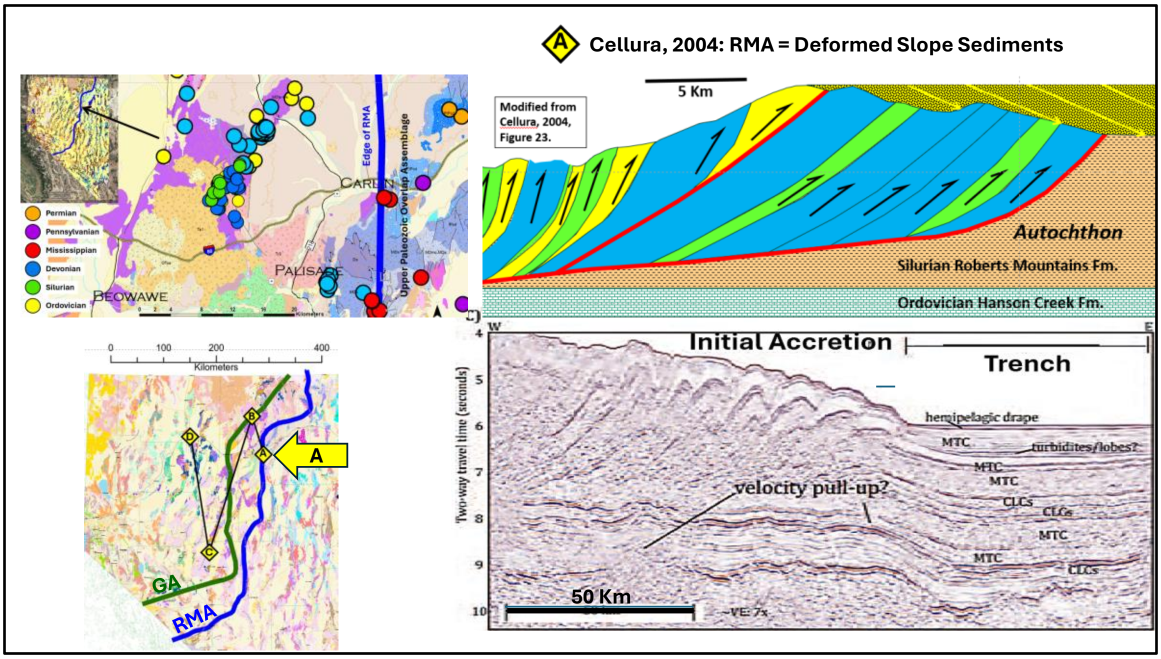
B Miller, 1984: Golconda Allochthon = Deformed Miss-Penn

C Babaie, 1987: Golconda Allochthon Deformed U.Paleozoic

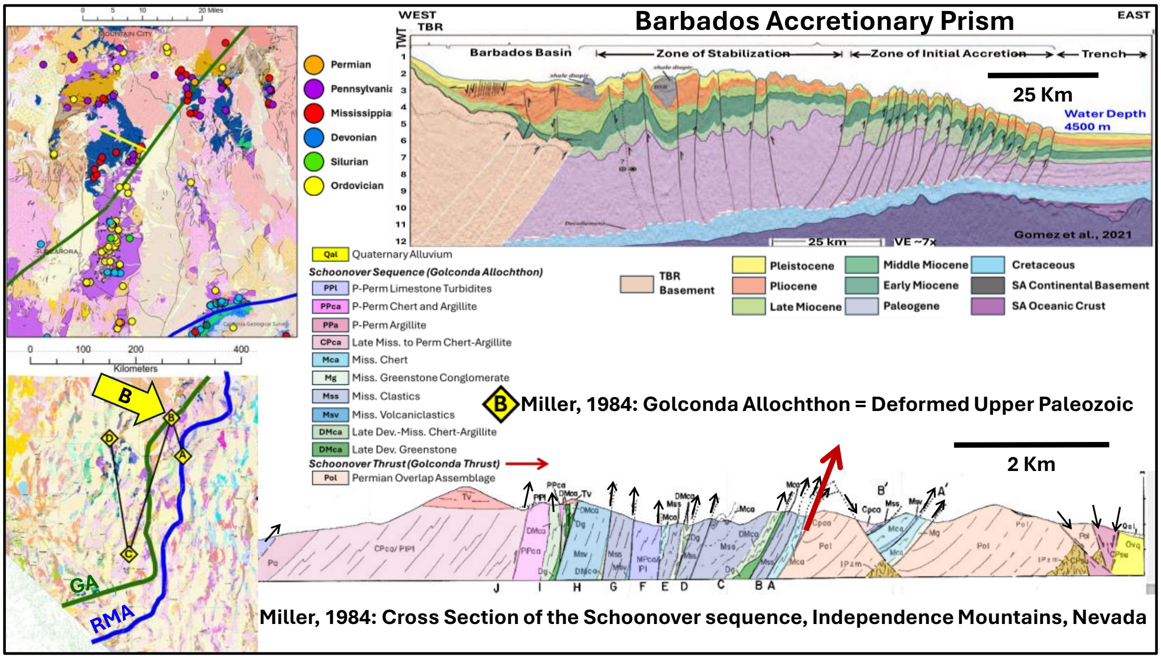
D Silberling, 1975: Golconda Allochthon = Deformed Triassic

Locations west of the edge of the Roberts Mountains Allochthon show a similar evolution of complexity. Section A shows imbricate thrusts overlain by undeformed overlap sediments. B shows near-vertical thrust faults that are deforming upper Paleozoic sediments. C shows continued rotation of thrusts to vertical and overturned orientations. D shows Triassic pull-apart basin sediments deformed by westward-directed compression.

Cellura, 2004: RMA = Deformed Slope Sediments



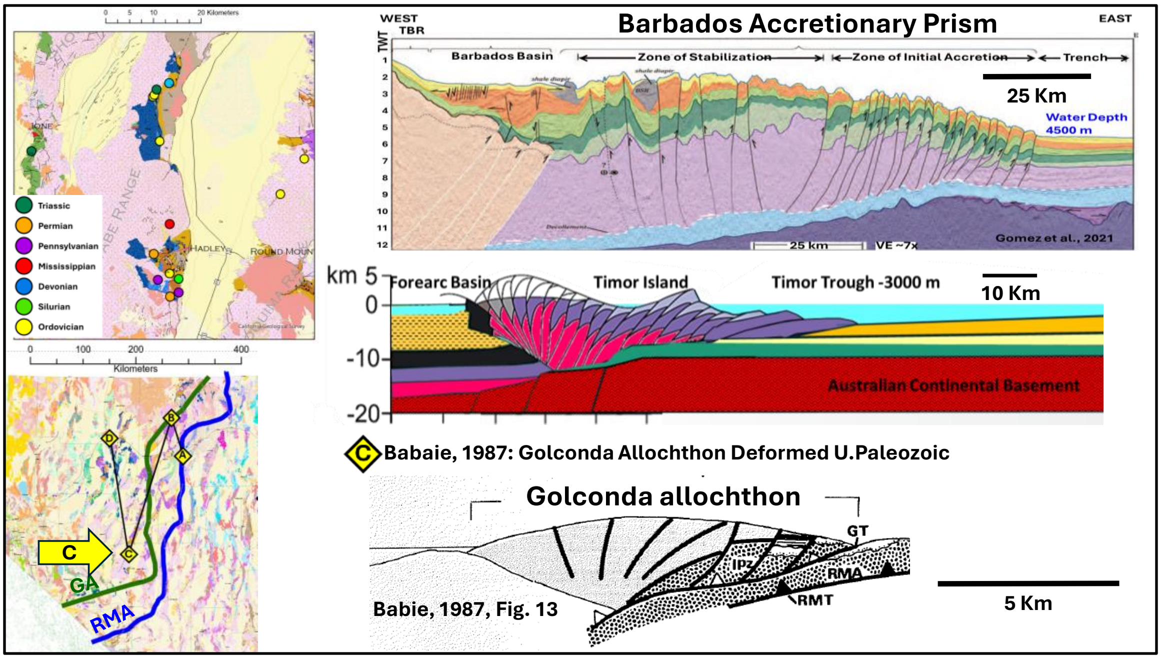
The simplest structures are imbricate thrusts at the leading edge of the allochthon.



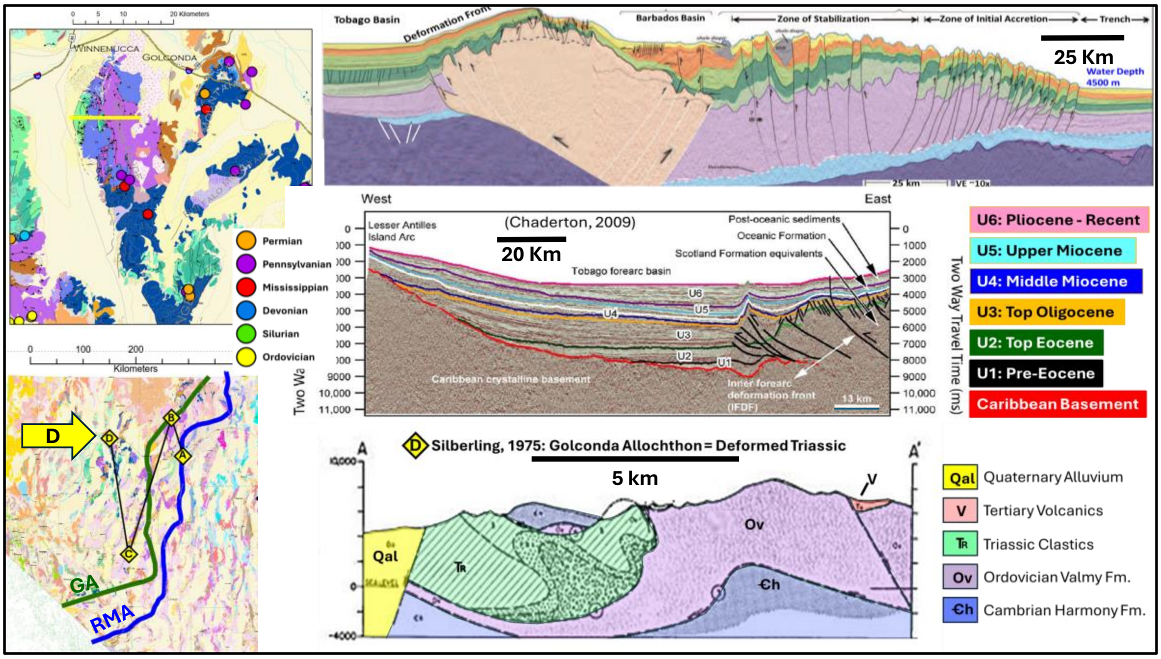
B Miller, 1984: Golconda Allochthon = Deformed Upper Paleozoic

Miller, 1984: Cross Section of the Schoonover sequence, Independence Mountains, Nevada

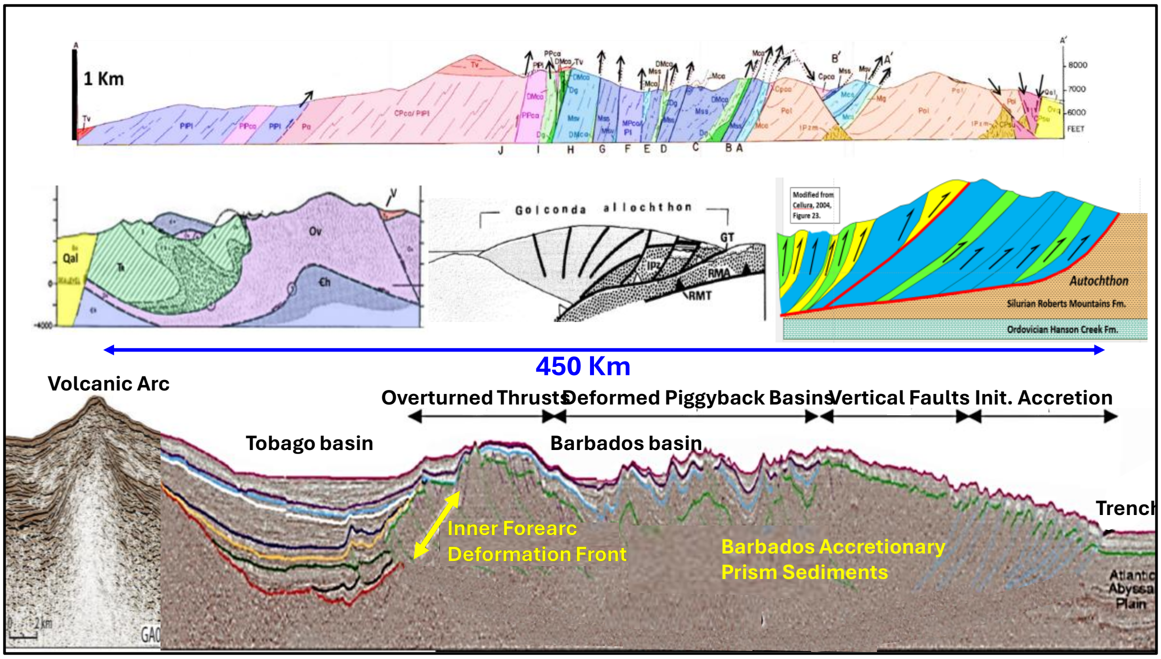
Section B lies at the edge of the Golconda Allochthon, consisting of Upper Paleozoic sediments cut by thrust faults that place Carboniferous rocks against and above Permian overlap clastics. The vertical faults in Miller's section correspond to the highly evolved stabilization zone of the Barbados prism.



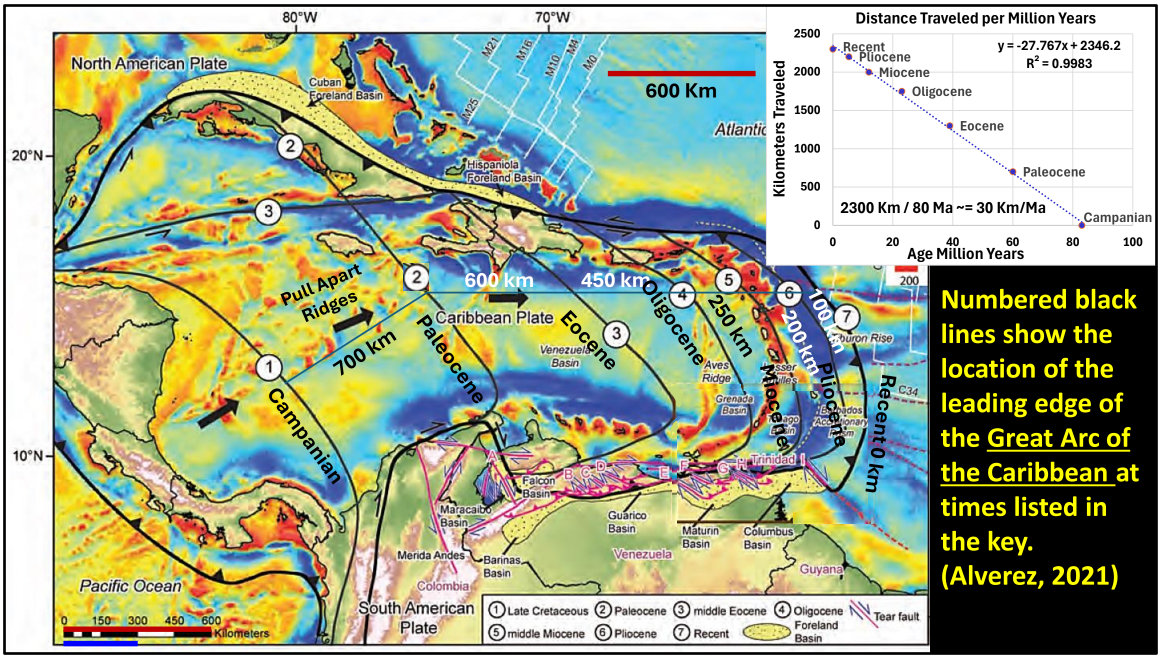
Section C lies behind the edge of the Golconda Allochthon. Here, the allochthon contains vertical thrust slices that become overturned farther to the west. This location compares to the very highly evolved portion of the Timor and Barbados accretionary prisms.



Section D is in the Sonoma Range, where Silberling defined the Sonoma Orogeny, a location far behind the edge of the Golconda Allochthon. Westward-directed thrust faults deformed Triassic volcaniclastic sediments deposited in a pull-apart basin. These resemble Tobago Basin forearc sediments deformed by thrusts at the far interior of the Barbados accretionary prism.

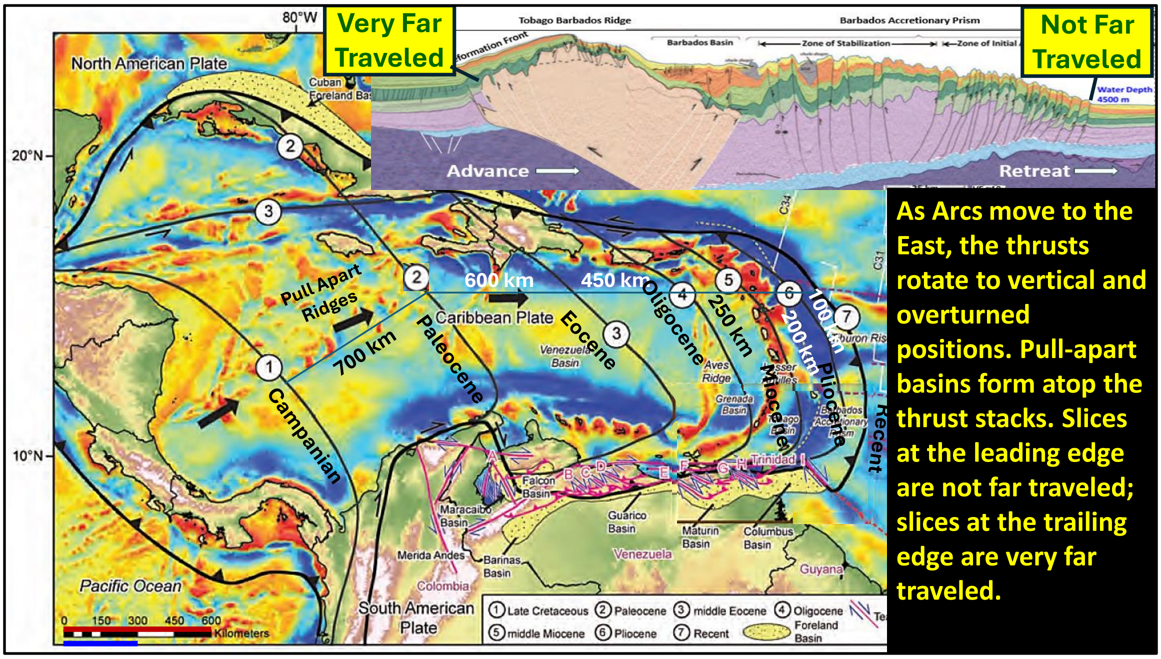


Structures become more highly evolved westward from the edge of the Roberts Mountains Allochthon, as with the Caribbean Arc system.



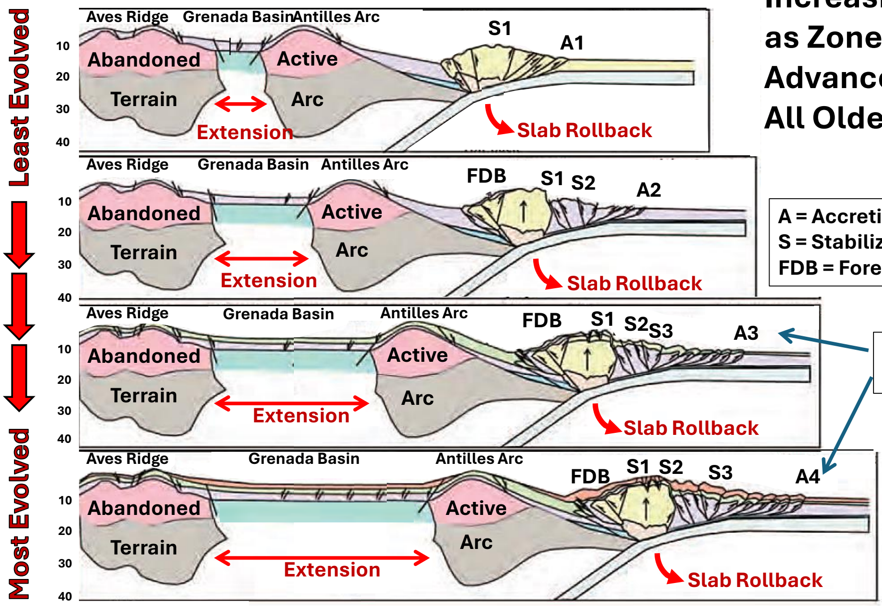
Numbered black lines show the location of the leading edge of the Great Arc of the Caribbean at times listed in the key. (Alverez, 2021)

The Great Arc of the Caribbean has moved over 2300 kilometers in 80 million years. The leading edge of the zone of initial accretion always looks the same. However, the older thrust slices behind the accretion zone have traveled greater distances.



As Arcs move to the East, the thrusts rotate to vertical and overturned positions. Pull-apart basins form atop the thrust stacks. Slices at the leading edge are not far traveled; slices at the trailing edge are very far traveled.

The youngest thrust slices at the leading edge of the allochthon have traveled only a few kilometers. Old slices at the trailing edge of the allochthon have traveled much farther. The thrusts at the front are not far traveled; the slices at the trailing edge have traveled thousands of kilometers.



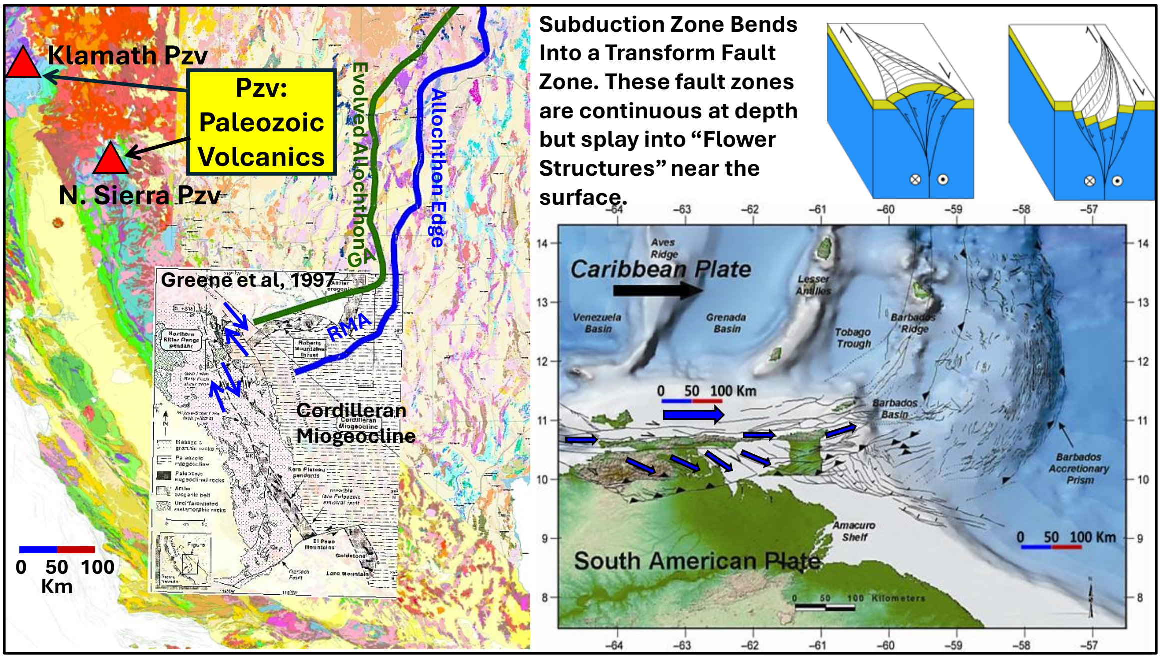
Increasing Complexity as Zone of Accretion Advances and Uplifts All Older Thrusts.

A = Accretion Zone
S = Stabilization Zone
FDB = Forearc Deformation Belt

Leading Edge Always Looks the Same.

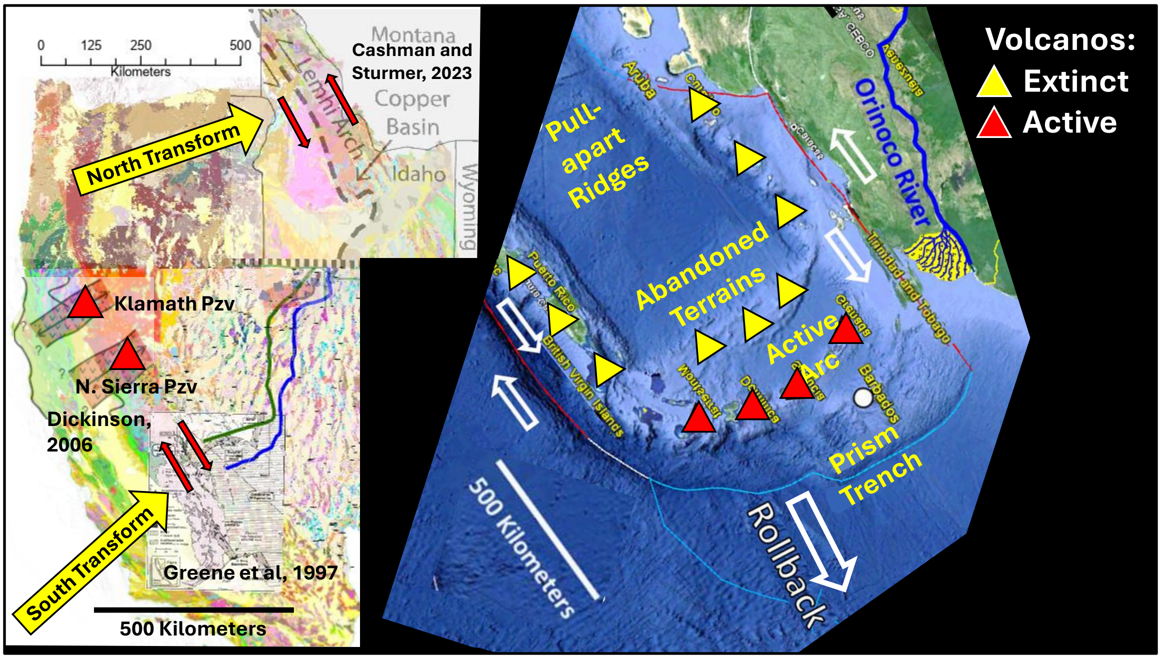
(Gomez et al., 2021)

The Laurentian Accretionary Prism contains structural domains comparable to the Great Arc of the Caribbean. The leading edge of the zone of accretion always looks the same. Once the thrusts rotate to vertical positions, the stabilization zone resembles the highly-evolved Golconda Allochthon. Slab rollback pulls the upper plate to the east, leading to tension and development of pull-apart basins and abandoned arc terrains.

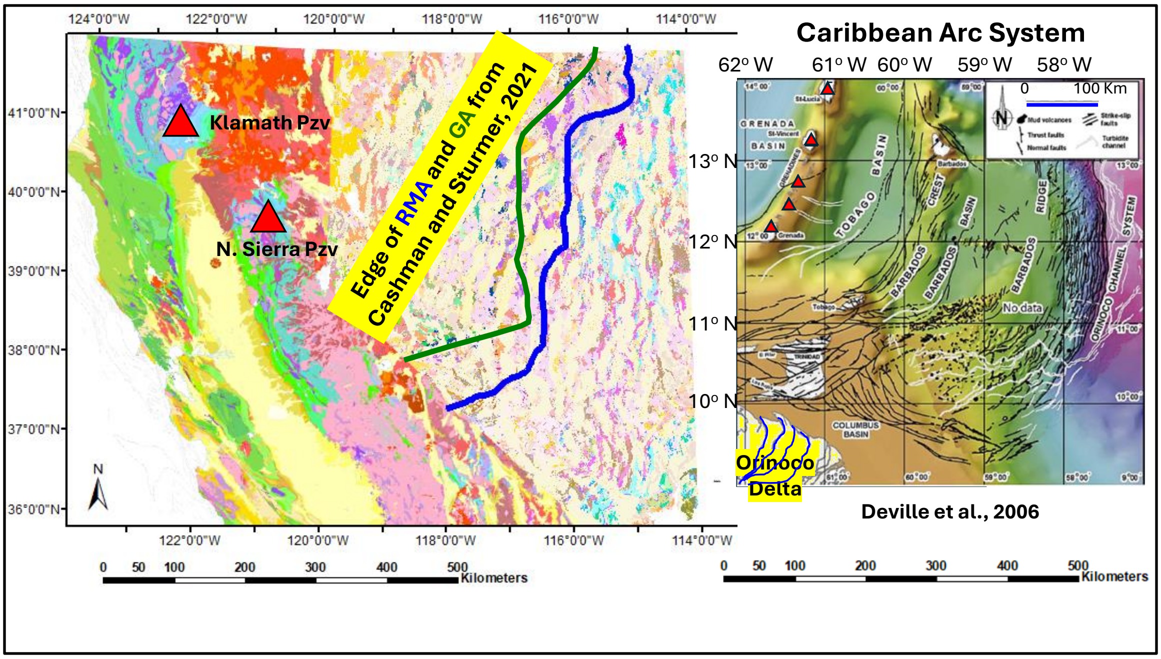


Subduction Zone Bends Into a Transform Fault Zone. These fault zones are continuous at depth but splay into “Flower Structures” near the surface.

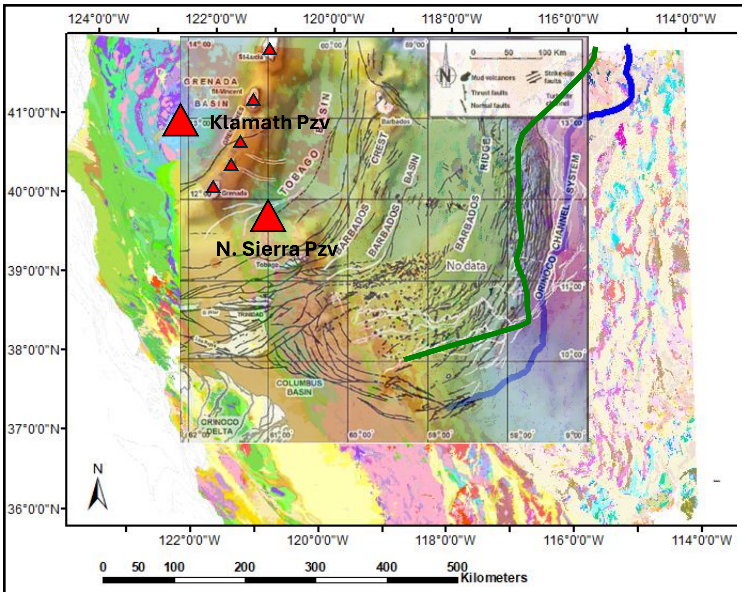
Transform faults are the sideboards of migrating arc systems. Diagrams tend to show a continuous bend where the trench curves into a transform fault. However, seismic lines show that the bend involves hundreds of small faults. Imagine the difficulty of following these faults across outcrops and into roof pendants of the Sierra Nevada batholith. This map from Greene overlies Cashman’s traces of the Roberts Mountains and Golconda allochthons.



North Transform is from Cashman and Sturmer, and the Klamath and North Sierra Arcs are from Dickinson. The Caribbean map is rotated to the approximate orientation of the West Laurentian Trench, which migrated thousands of kilometers over 10's of millions of years. The leading edge is a simple zone of accretion. But the prism becomes more highly evolved toward the volcanic arc. Fragments of abandoned prisms and arcs likely remain behind the migrating system; these may represent areas described as separate terrains, like the Klamath and South Sierra terrains.



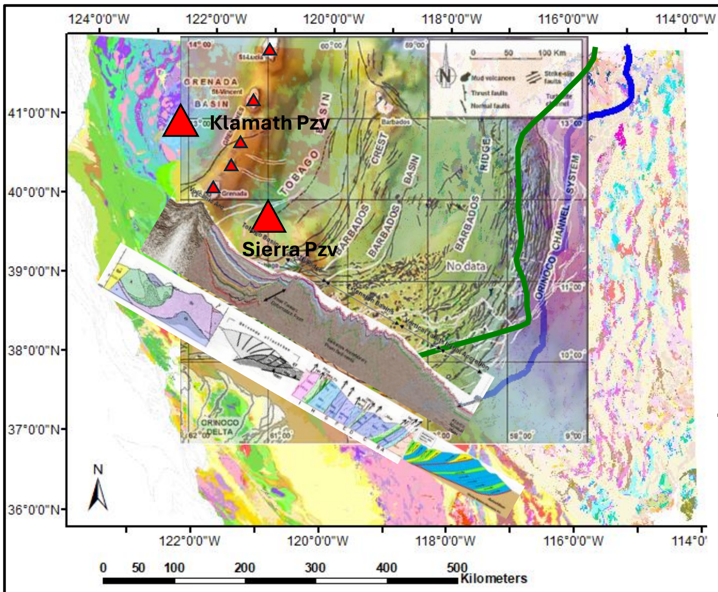
I'll overlay the Caribbean map on Nevada at the same scale.



Laurentian Passive Margin did not collide with an Island Arc, it collided with a migrating ocean trench.

The curve of the volcanic Island Arc paralleled the curve of the subduction trench. The volcanic Arc was located over 400 kilometers behind the trench.

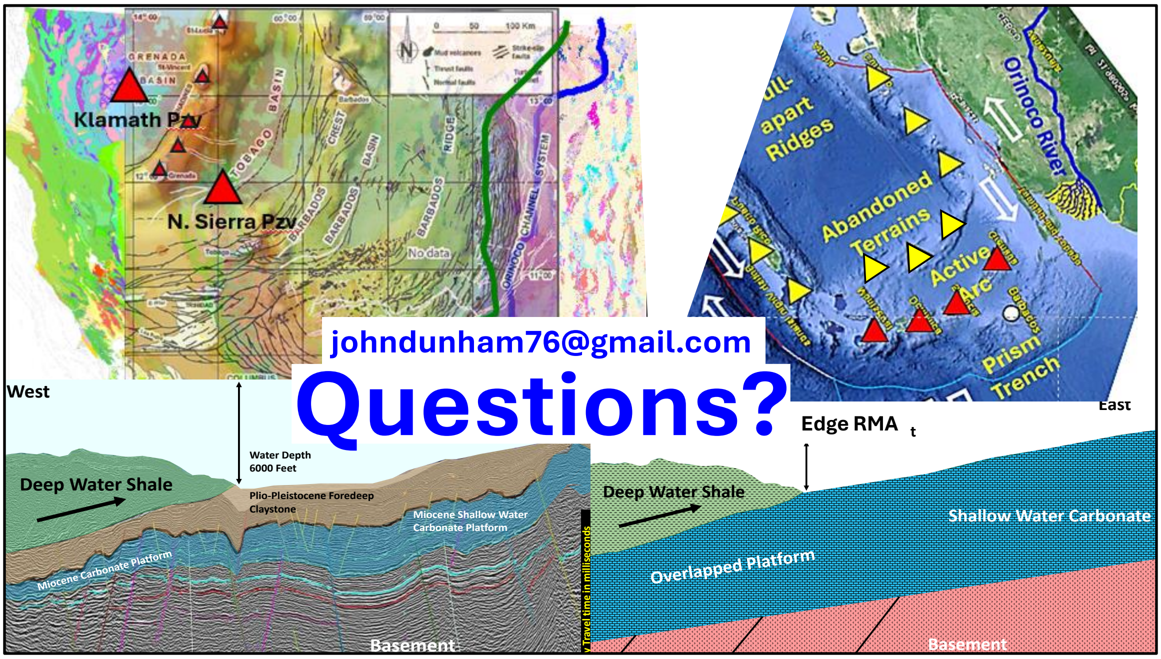
The overlay is oriented with the leading edge of the RMA aligned with the leading edge of the Barbados accretionary prism. The Laurentian Passive Margin did not collide with an Island Arc; it collided with a subduction trench.



Previous authors have proposed tectonic transport of thrust slices along the Laurentian margin, including Linde et al. (2016, 2017) and Chen and Clemens-Knott (2021).

My presentation illustrates the process. The allochthon is over 400 km wide; its motion driven by gravity-induced slab rollback.

The interpretation is that the leading edge of the Roberts Mountains Allochthon is a subduction trench. The space between the trace of the Roberts Mountains and the Golconda Allochthons corresponds to the relatively simple zone of initial accretion. The Golconda allochthon conforms to the highly evolved zone of vertical and overturned thrust faults. Pull-apart basins formed atop the allochthon, and sediments accumulating within these basins became deformed by continuous plate movement. A volcanic arc parallels the subduction trench, over 400 kilometers behind the trench. Previous authors have suggested this model, but my presentation shows how it likely happened.



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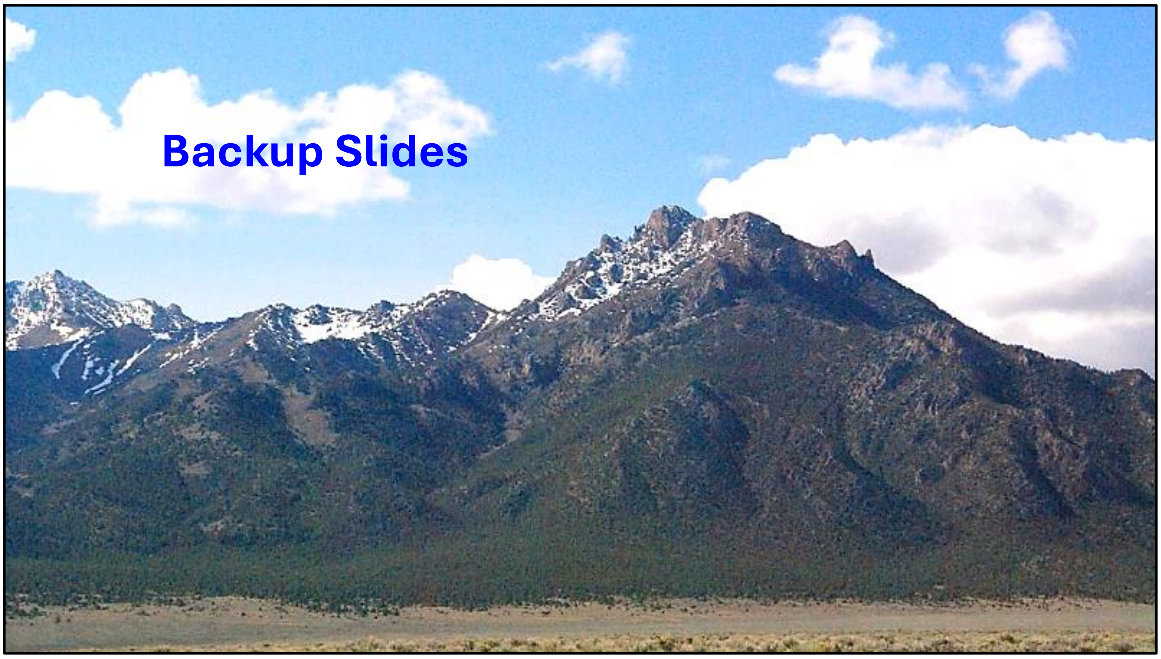
Questions?

And to grad students just getting started, I hope that 50 years from now, you'll be giving a talk at GSA Connects. Are there any questions?

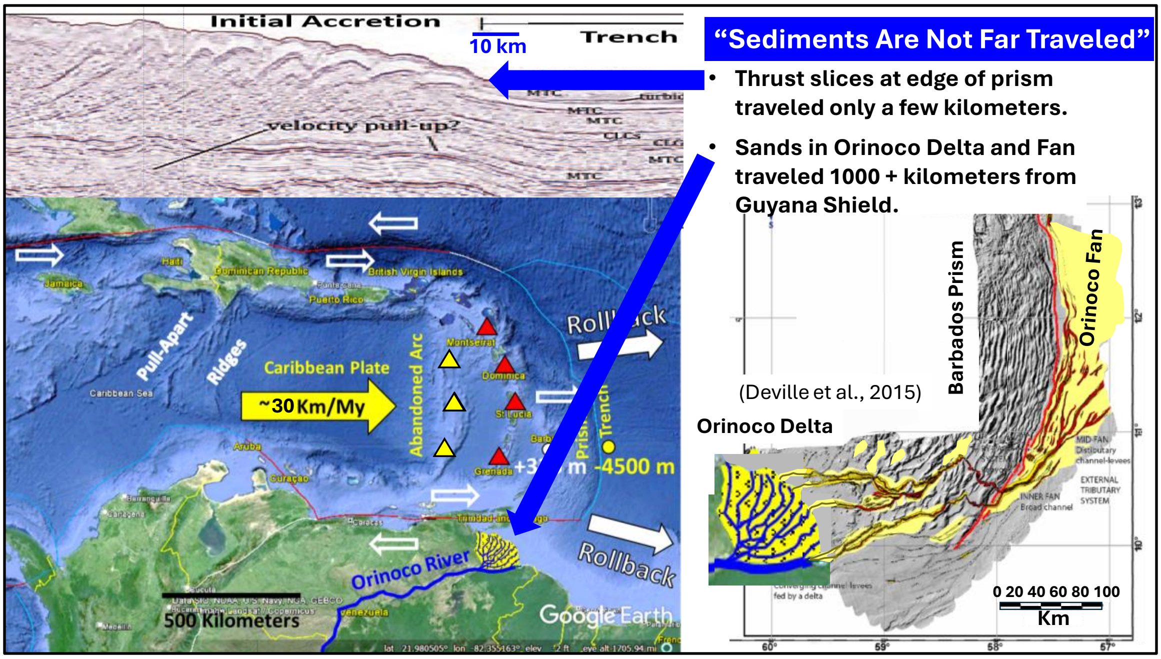
Download Presentation and Reference List:

https://Github.com/jdunham76/Anaheim24



Backup Slides

Backup Slides to address questions.

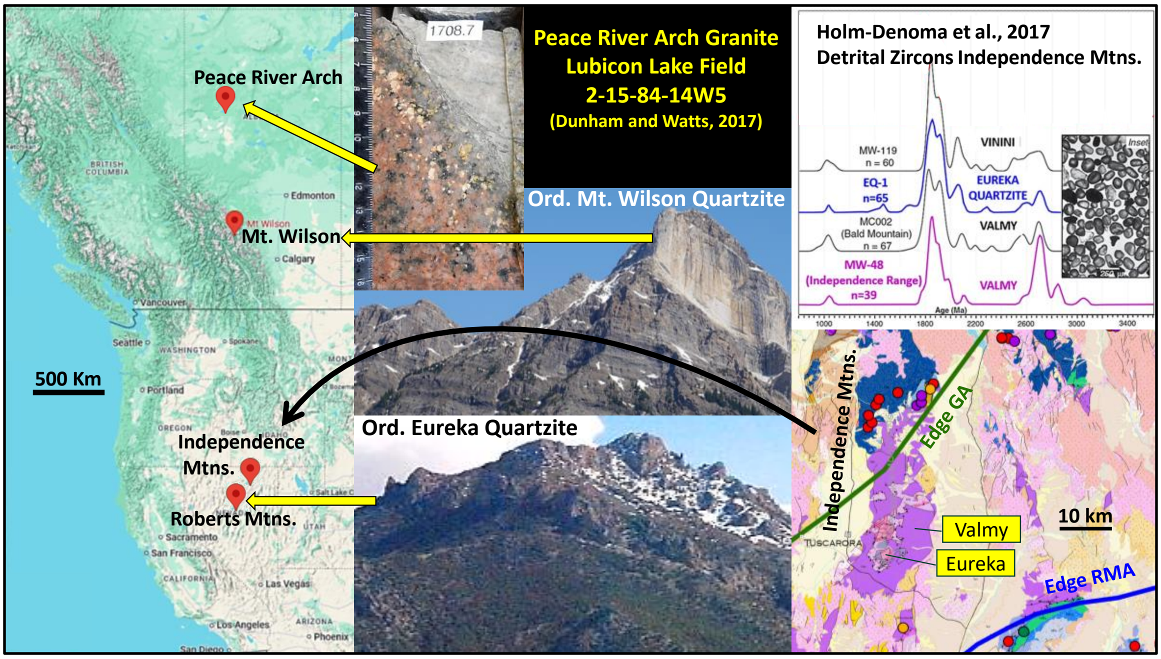


"Sediments Are Not Far Traveled"

- Thrust slices at edge of prism traveled only a few kilometers.
- Sands in Orinoco Delta and Fan traveled 1000 + kilometers from Guyana Shield.

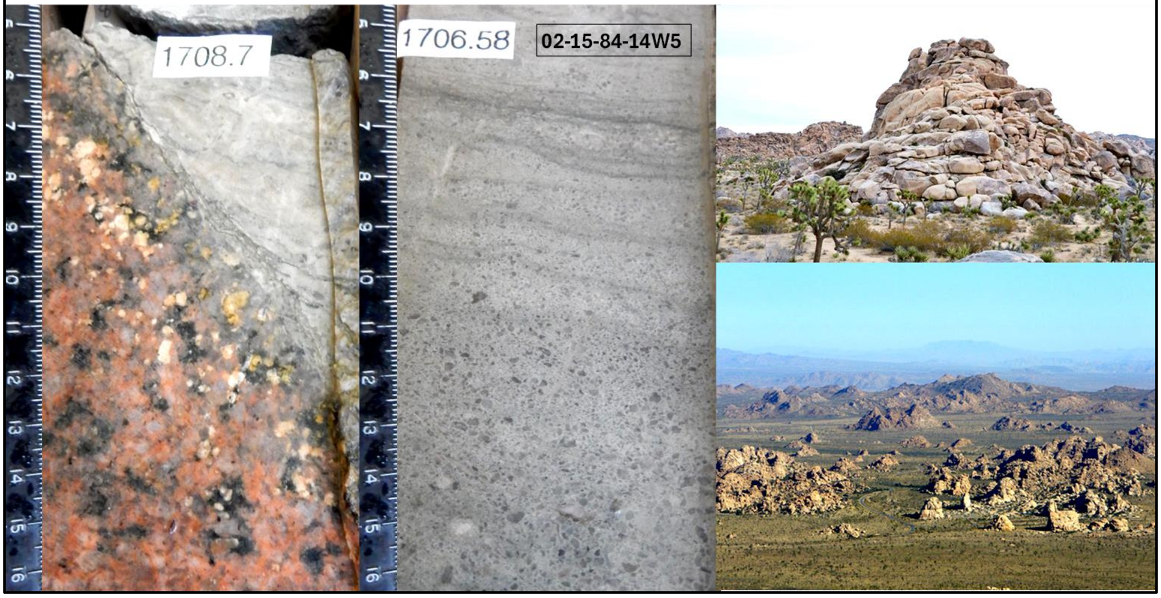
(Deville et al., 2015)

Sediments in thrust slices at the edge of the prism have only traveled a few kilometers. However, sand grains from the Orinoco River have traveled over a thousand kilometers from the Guyana Shield. The distinction is between tectonic transport of thrust slices as opposed to water transport of sand grains.

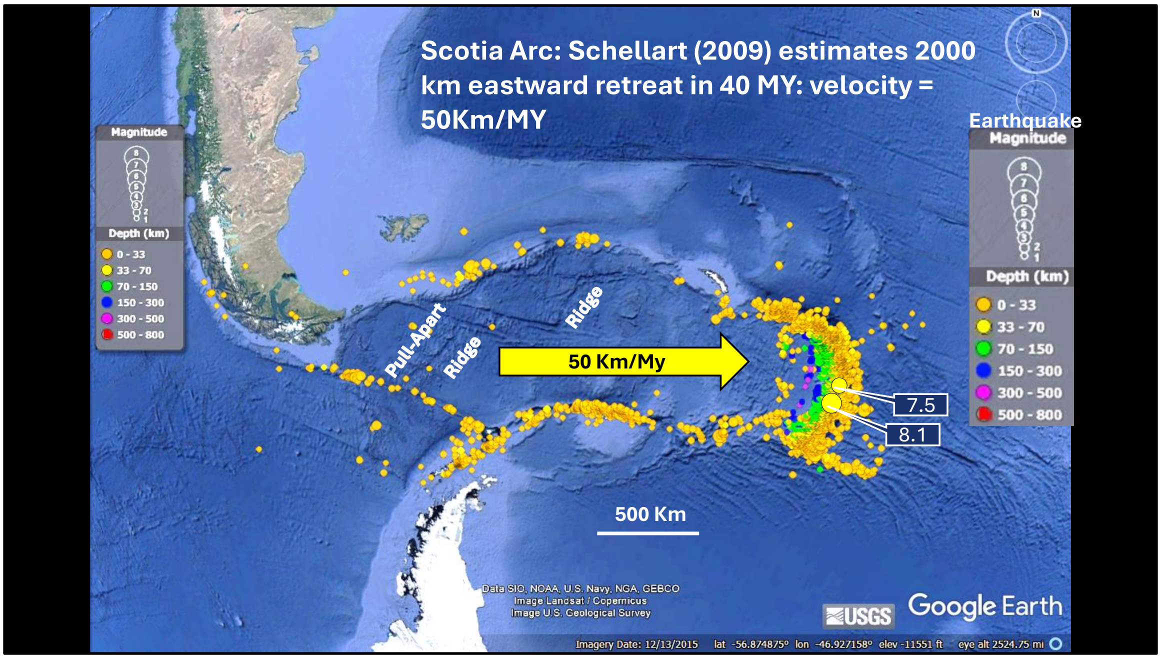


This slide illustrates the not far traveled issue. The quartz grains in the Eureka Quartzite traveled thousands of kilometers from the Peace River Arch along the Laurentian Continental Shelf by means of Long Shore Drift. The quartz grains in the Valmy formation are submarine fan sands deposited on the Laurentian Continental Slope, downslope from the Eureka Quartzite. The map insert shows Eureka Quartzite in the lower plate, overlain by Valmy sands in the upper plate of the RMA, in a thrust slice that has traveled only a few kilometers near the edge of the RMA. These are the two different modes of “far, not far, traveled”.

(Dunham and Watts, 2017)

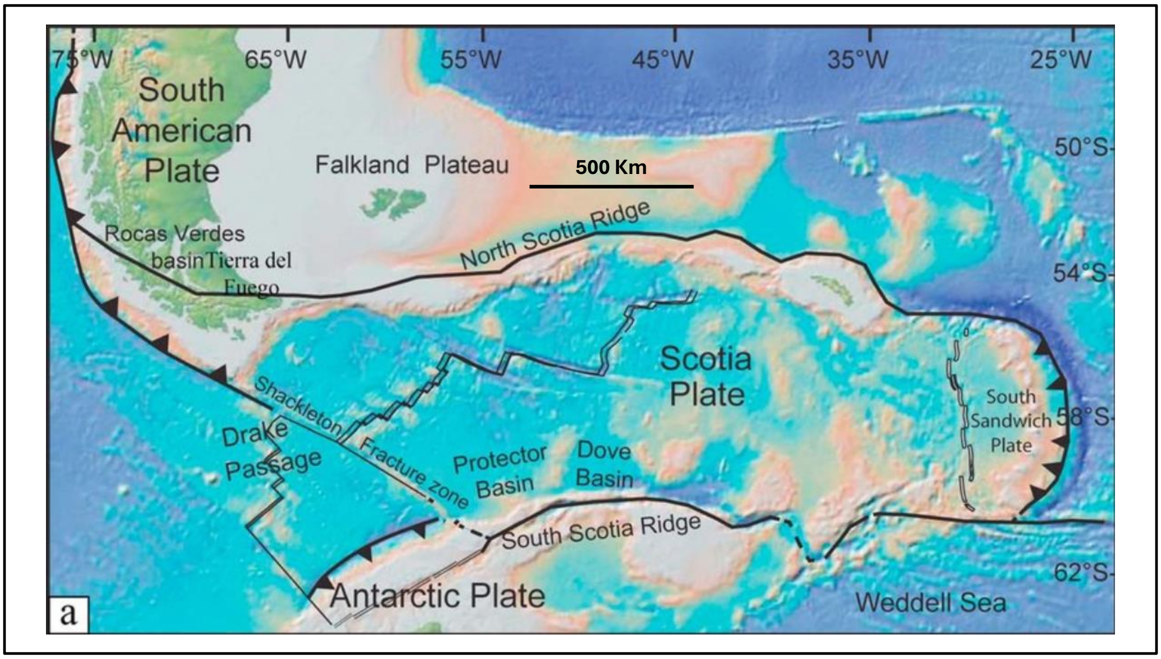


Granite of the Peace River Arch weathers into Granite Wash sand composed of angular quartz, feldspar, biotite, and rock fragments. Ketner suggested this as the source for the Eureka Quartzite in Nevada. By the time it gets to Nevada, it will be very well-rounded pure quartz sand.

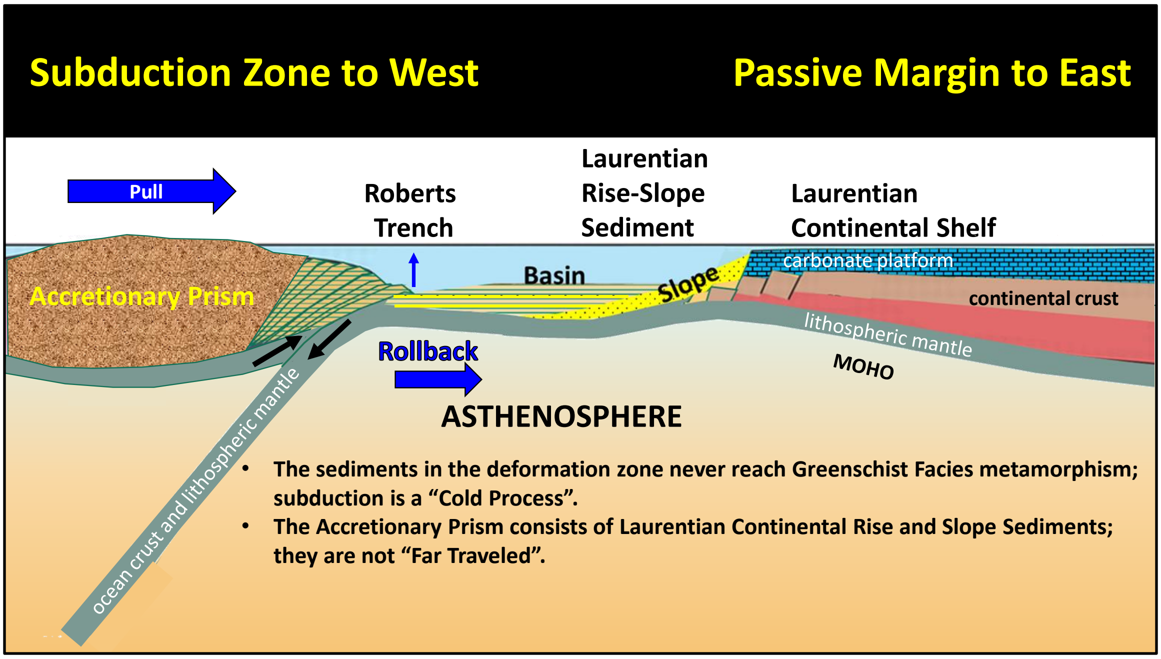


Scotia Arc: Schellart (2009) estimates 2000 km eastward retreat in 40 MY: velocity = 50Km/MY

What mechanism drove the migration of the subduction trench? Where are the transform faults that bound the trench? The direction of motion of the migrating system is delineated by the position of the volcanic arc relative to the trench. The arc always moves toward the trench. The trench does not move toward the arc. Make a map showing the arc and the trench, and then put an arrow leading from the arc to the trench. In the case or the RMA, the arc lies northwest of the trench, therefore the system mograted from north to south. It could not have migrated from south to north, because in that case the arc would be south of the trench, which it is not.



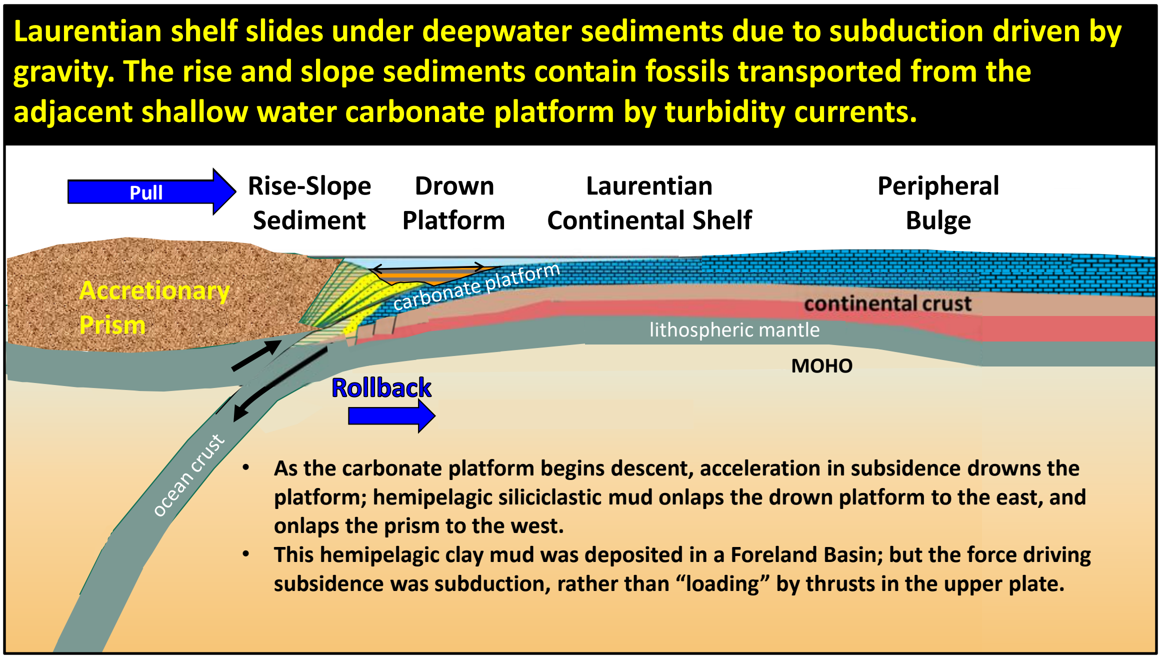
Detail of back arc pull-apart ridges and abandoned terrains behind Scotia Arc.



Subduction Zone to West **Passive Margin to East**

- **The sediments in the deformation zone never reach Greenschist Facies metamorphism; subduction is a “Cold Process”.**
- **The Accretionary Prism consists of Laurentian Continental Rise and Slope Sediments; they are not “Far Traveled”.**

A model for the evolution of the Roberts Mountains Allochthon: slab rollback causes a west-dipping subduction zone to retreat toward the Laurentian continental shelf. Sediments of the slope and basin contain material transported from the shelf.

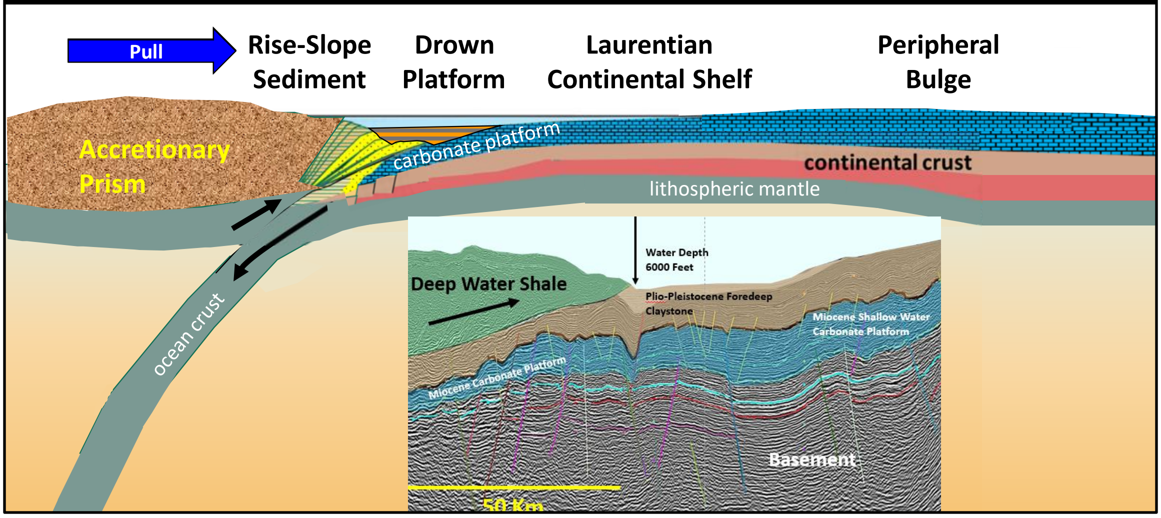


Laurentian shelf slides under deepwater sediments due to subduction driven by gravity. The rise and slope sediments contain fossils transported from the adjacent shallow water carbonate platform by turbidity currents.

- **As the carbonate platform begins descent, acceleration in subsidence drowns the platform; hemipelagic siliciclastic mud onlaps the drown platform to the east, and onlaps the prism to the west.**
- **This hemipelagic clay mud was deposited in a Foreland Basin; but the force driving subsidence was subduction, rather than "loading" by thrusts in the upper plate.**

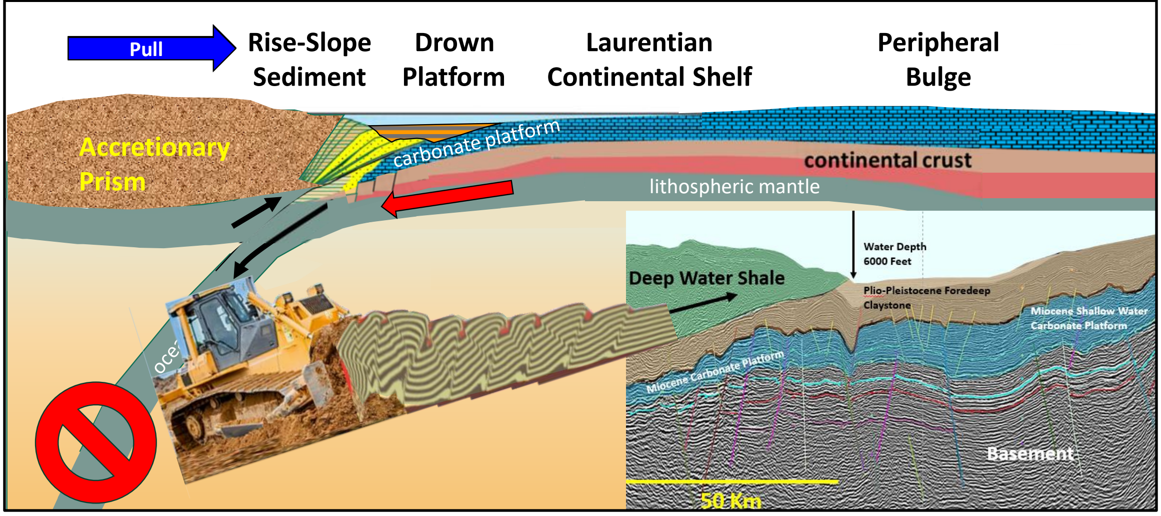
The shallow-water carbonate platform descends into the trench and slides below the accretionary prism, resulting in emplacement of a stack of imbricately thrusted deep-water sediment atop shallow-water carbonate platform sediment. Gravity drives the process; the platform falls under the prism. Slab rollback pulled the prism eastward; while the platform fell westward into the trench.

Laurentian shelf slides under deepwater sediments due to subduction driven by gravity. The rise and slope sediments contain fossils transported from the adjacent shallow water carbonate platform by turbidity currents.



This process is happening at continental margins in Recent time.

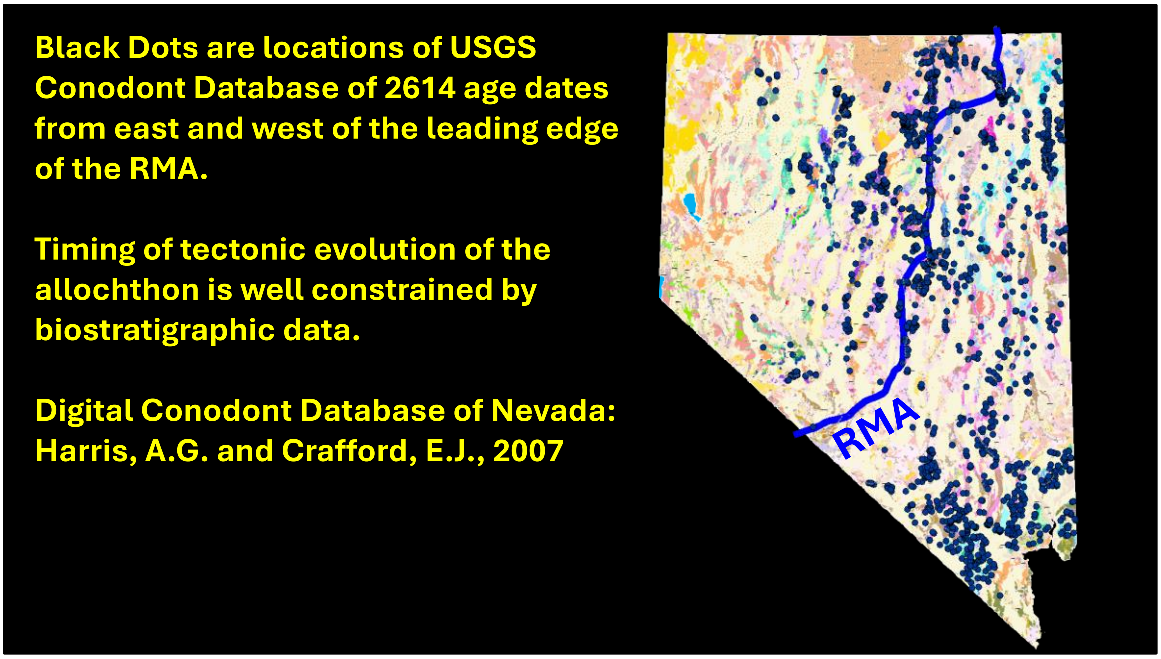
Laurentian shelf slides under deepwater sediments due to subduction driven by gravity. The rise and slope sediments contain fossils transported from the adjacent shallow water carbonate platform by turbidity currents.



You don’t need a bulldozer to push deepwater sediment onto the carbonate platform. Rather, gravity drives the process as the platform falls into the trench.

Overlap sediments in the Garden Valley Fm. contain carbonates with large fusilinids and abundant red and green chert clasts eroded from the Vinini Formation. This is analogous to subaerially exposed Timor and Barbados accretionary prisms.

Analogous to Timor Island, traces of an uplifted Pennsylvanian landmass in Nevada are seen in coarse “mollase” deposits containing eroded deep-water radiolarian chert clasts and shallow water fusilinid limestones.



Black Dots are locations of USGS Conodont Database of 2614 age dates from east and west of the leading edge of the RMA.

Timing of tectonic evolution of the allochthon is well constrained by biostratigraphic data.

Digital Conodont Database of Nevada: Harris, A.G. and Crafford, E.J., 2007

USGS Conodont Database of Nevada.

Deep-sea origin of Ordovician pillow basalt and associated sedimentary rocks, northern Nevada: CHESTER T. WRUCKE, MICHAEL CHURKIN, CHRIS HEROPOULOS J, US. Geological Survey: GSA Bulletin, v. 89, p. 1272-1280

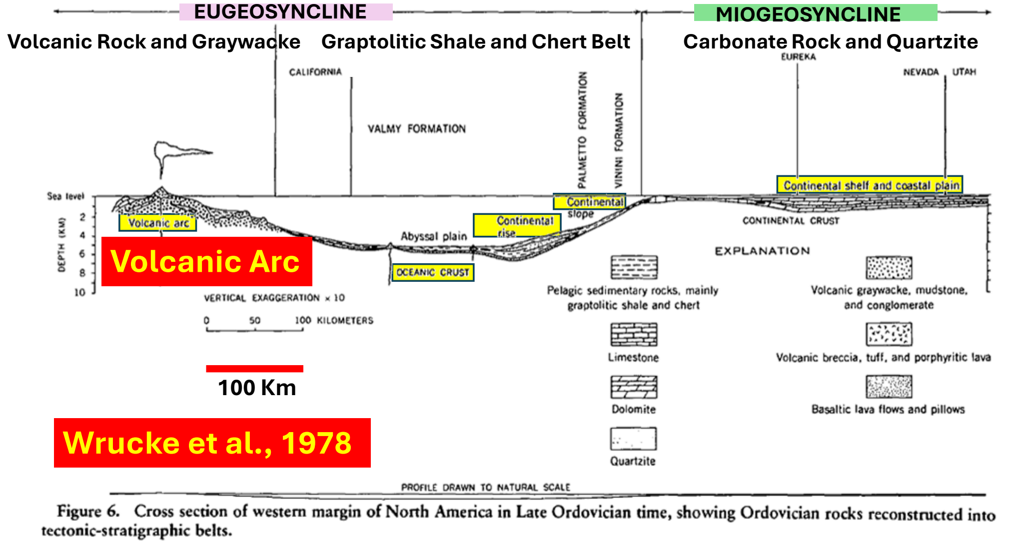
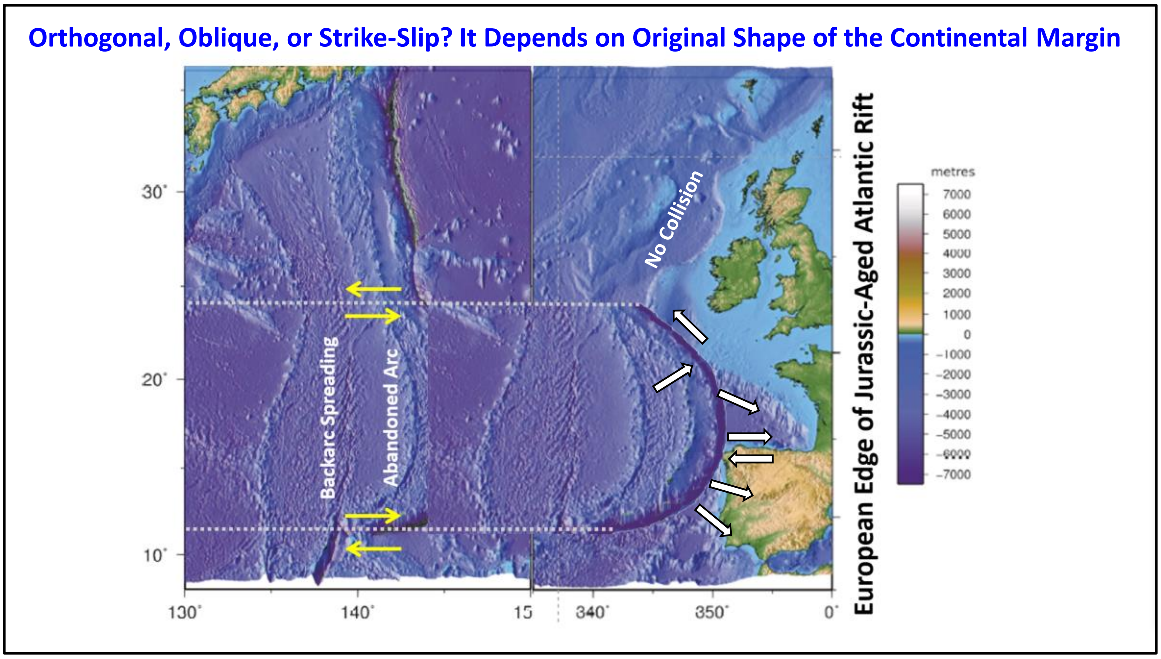


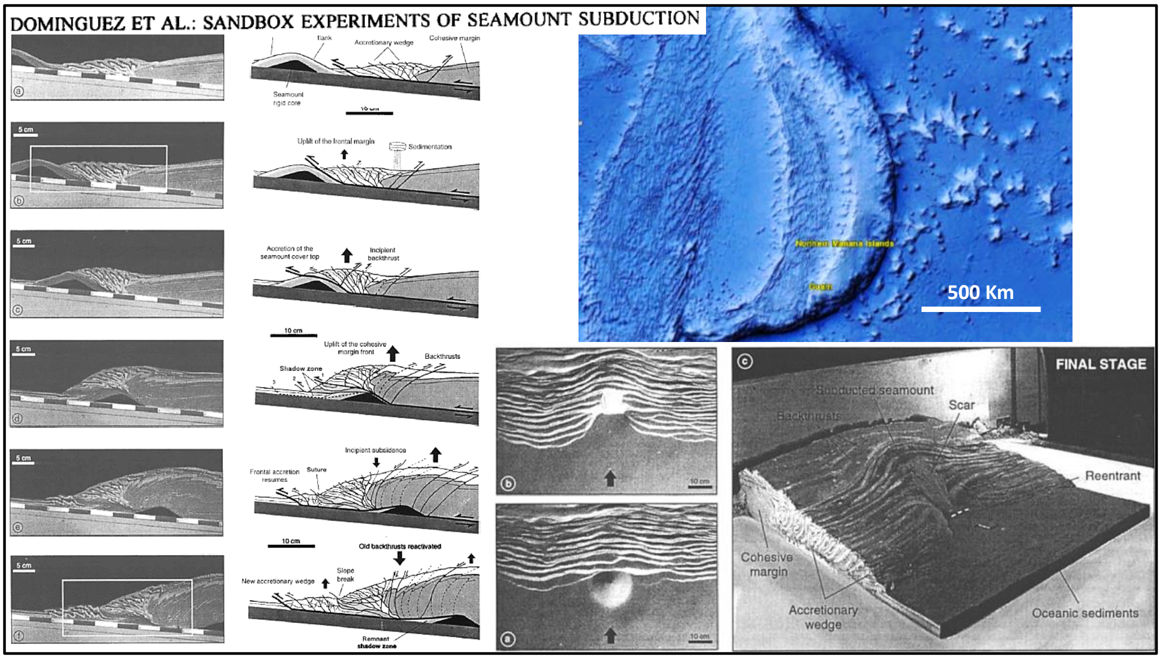
Figure 6. Cross section of western margin of North America in Late Ordovician time, showing Ordovician rocks reconstructed into tectonic-stratigraphic belts.

Paleozoic volcanic rocks are present west of the carbonate platform and accretionary prism. This prescient cross section was published in 1978 by the USGS; it has almost all the elements of this story, including the Volcanic Island Arc to the west. The only thing it lacks is a drawing of a west dipping subduction zone under the arc. It was compiled from the locations of Paleozoic volcanic rocks in Nevada and eastern California.



Orthogonal, Oblique, or Strike-Slip? It Depends on Original Shape of the Continental Margin

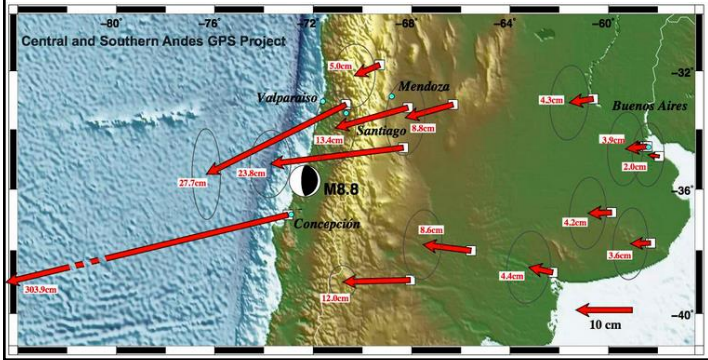
Whether the collision is orthogonal, oblique-slip, or pure strike-slip depends on the original shape of the continental margin.

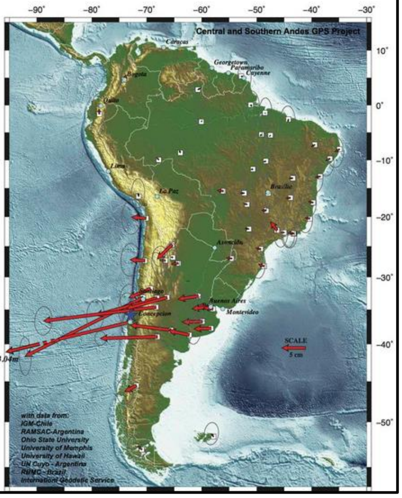


Seamounts are abundant on ocean crust, and they are subducted in ocean trenches. They create anomalous zones in accretionary prisms.

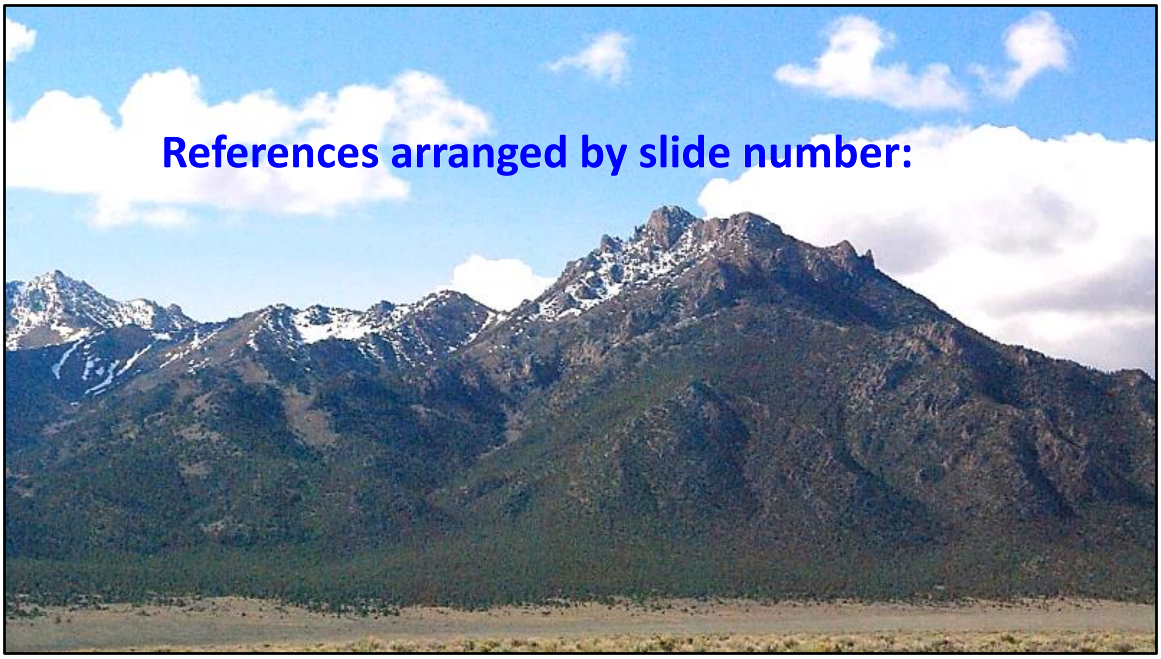
A magnitude 8.8 earthquake in Chile moved the city of Concepcion 3 meters westward.

https://spotlight.unavco.org/station-pages/conz/conz.html





Magnitude 8.8 earthquake in Chile moved GPS stations up to 3 meters to the west. Stations far east of the quake also moved west.



References arranged by slide number:

Backup Slides to address questions.

Slide	Topic	Reference
1	Geologic Map of Nevada	Crafford, A., 2008, Paleozoic tectonic domains of Nevada: An interpretive discussion to accompany the geologic map of Nevada: Geosphere, V. 4, no. 1, p. 260-291; doi: 10.1130/GES00108.1
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18	Barbados Accretionary Prism	Gomez, S., T. Alvarez, P. Mann, and A. Krueger, 2021, Tectono-stratigraphic evolution of the Barbados accretionary prism and surrounding sedimentary basins within the southeastern Caribbean, arcuate, strike-slip-to-subduction transition zone, in C. Bartolini, ed., South America–Caribbean–Central Atlantic plate boundary: Tectonic evolution, basin architecture, and petroleum systems: AAPG Memoir 123, p. 265–316; DOI: 10.1306/13692248M1233850
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Backup Slide Section		
45	Orinoco Delta and Fan	Deville, E., Mascle, A., Callec, Y., Huyghe, P., Lallemant, S., Lerat, O., Mathieu, X., Padron de Carillo, C., Patriat, M., Pichot, T., Loubrieux, B., and Granjeon, D., 2015, Tectonics and sedimentation interactions in the east Caribbean subduction zone: An overview from the Orinoco delta and the Barbados accretionary prism, Marine and Petroleum Geology, v. 64, p. 76-103; doi: 10.1016/j.marpetgeo.2014.12.015
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