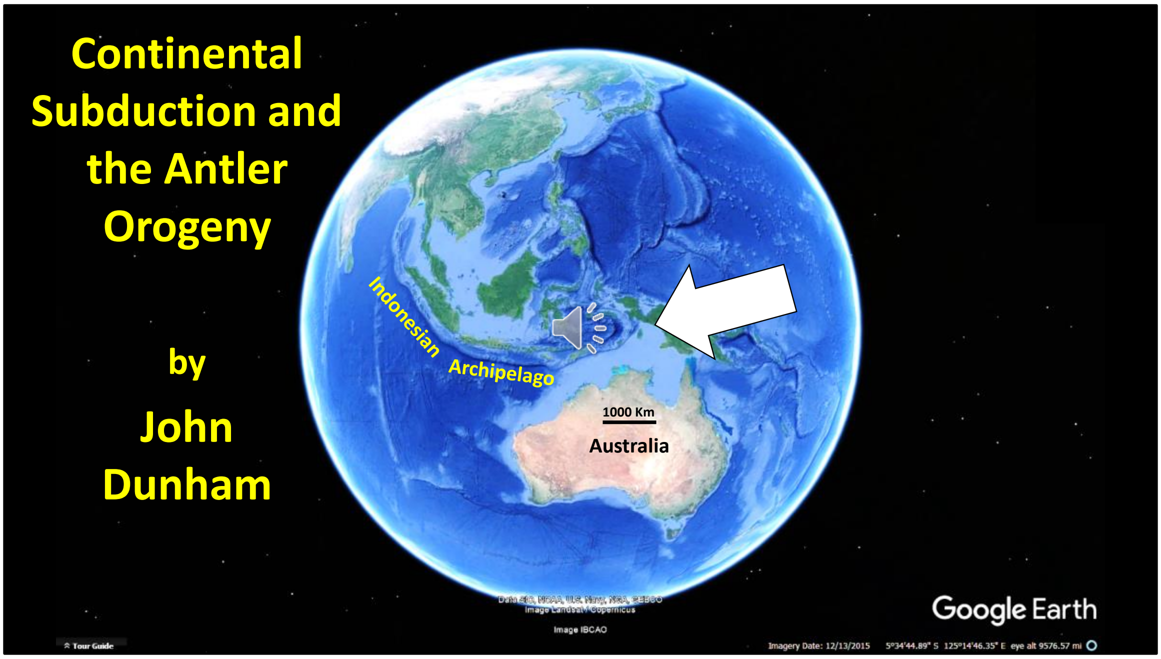
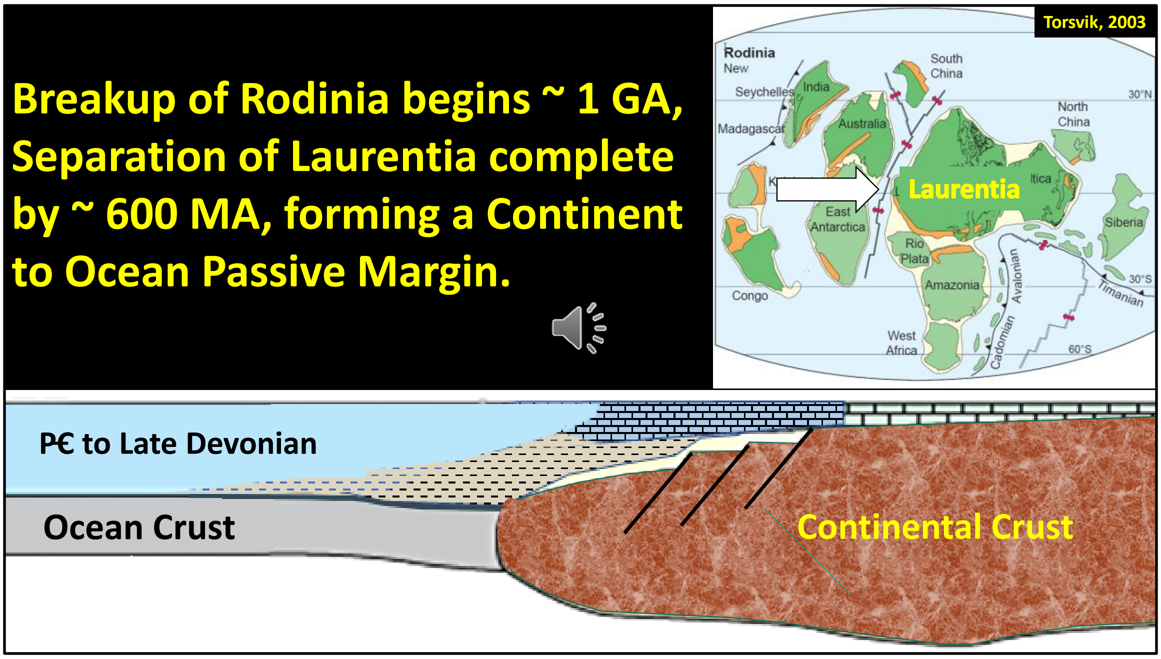
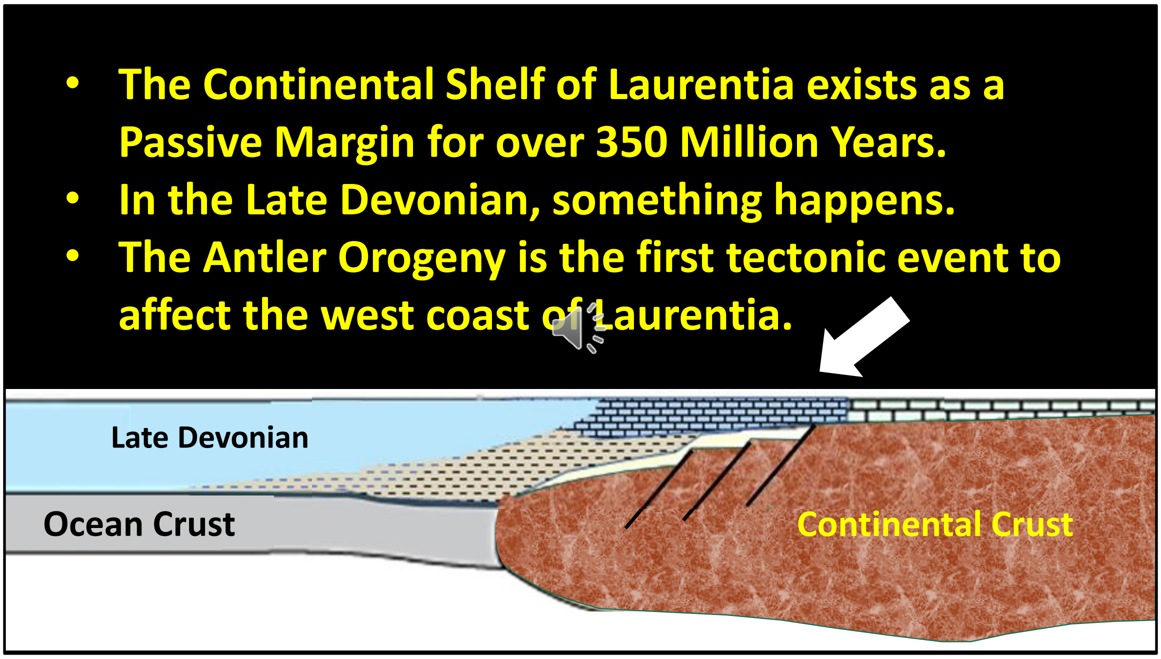


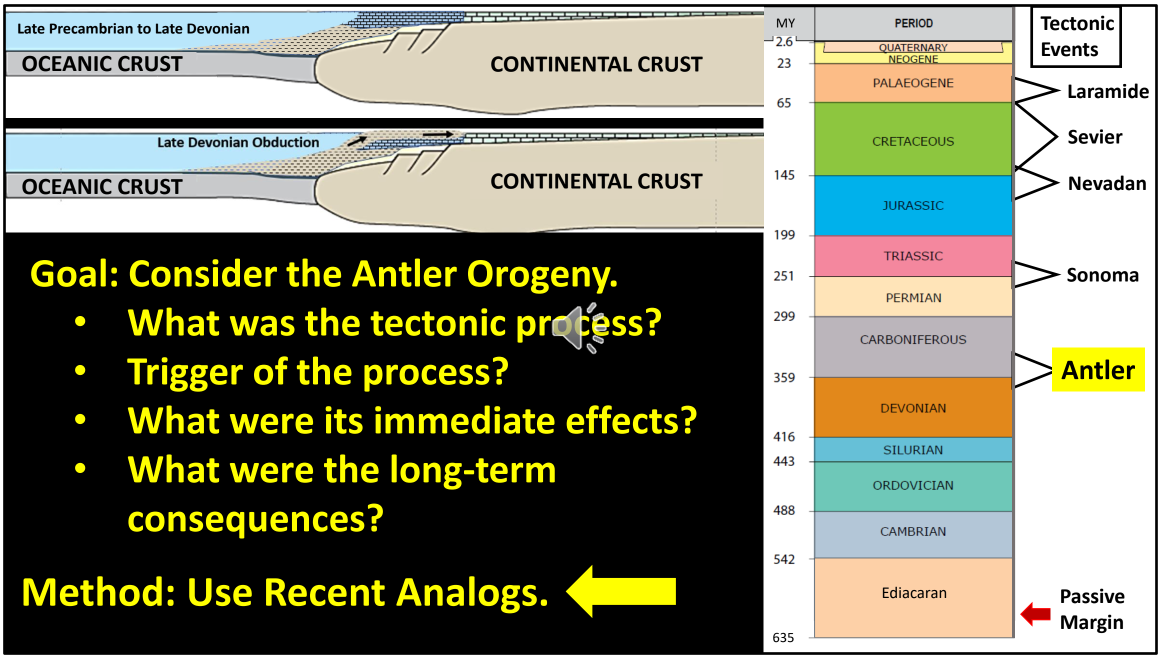
The Antler Orogeny was the first tectonic event to affect Western North America since Precambrian rifting. This talk uses Recent analogs to infer the process. The slide animations are meant to draw your eye to details without using a pointer.



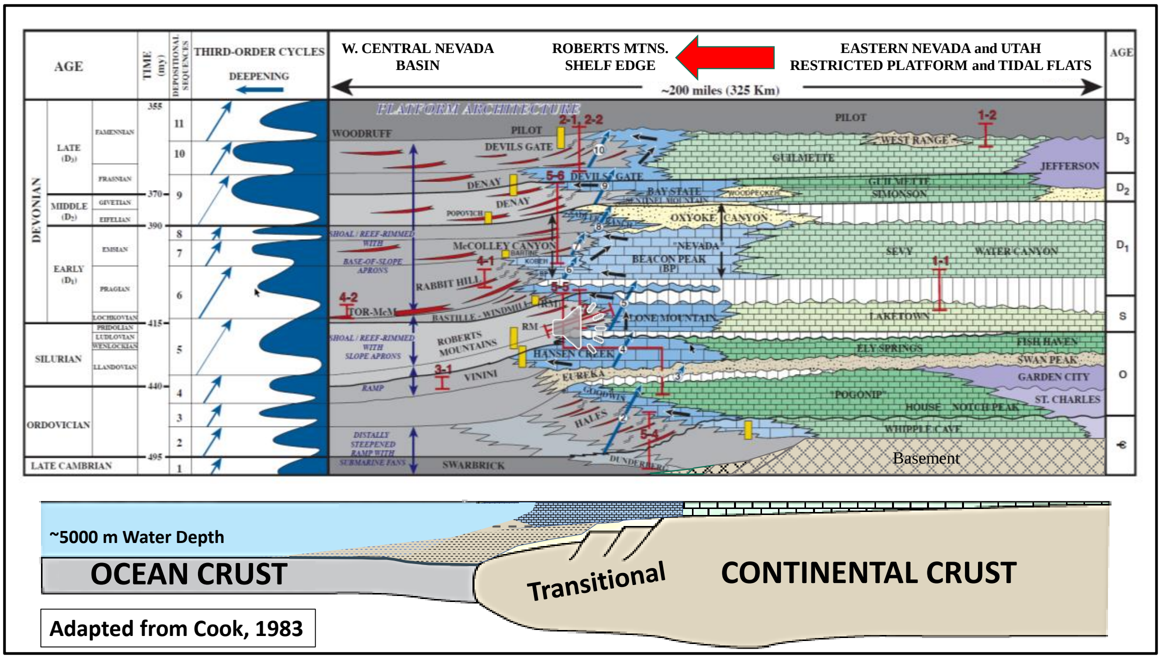
The breakup of Rodinia begins in Late Precambrian and separation of Laurentia is complete by about 600 MY, forming a Continent to Ocean passive margin.



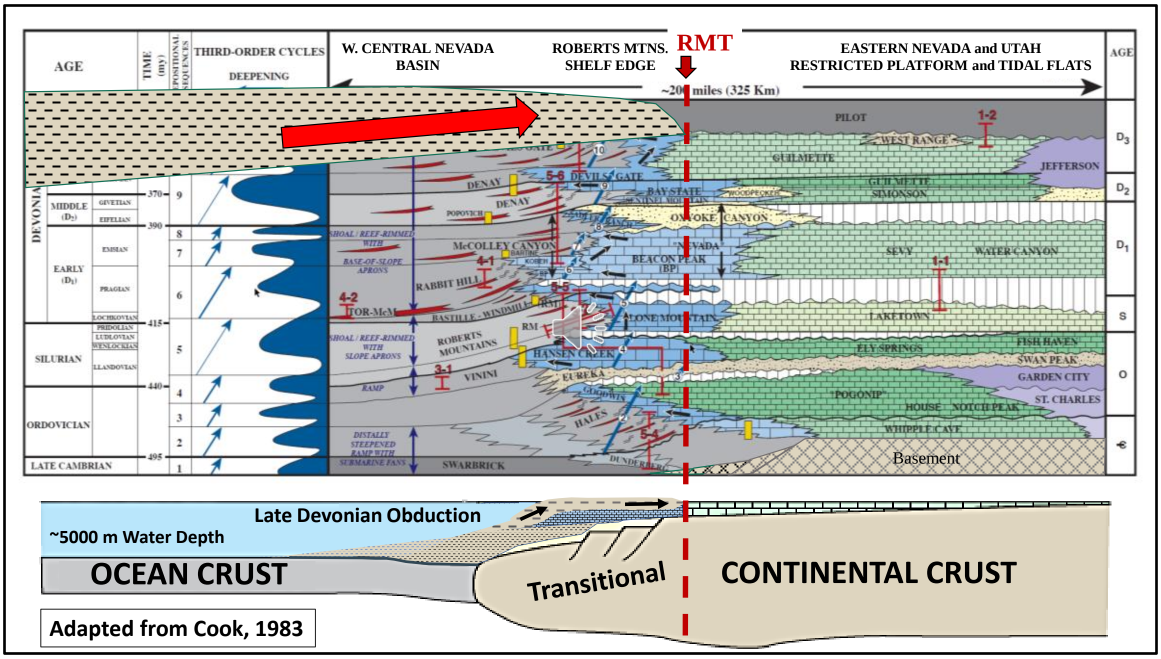
The Antler Orogeny obducted deep-water clay shale onto shallow water carbonate platform sediment. The Roberts Mountains thrust is the base of the allochthon. How did this happen?



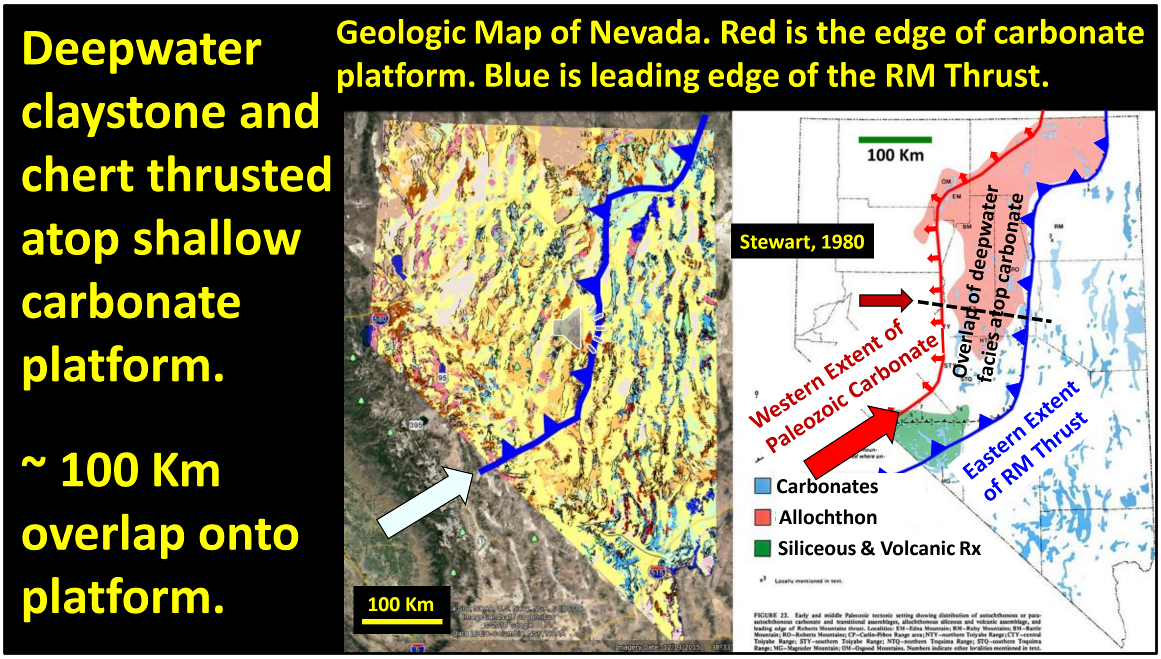
Many papers discuss the Antler event, most involving collision with an island arc, though some propose east-dipping subduction while others suggest west-dipping. All agree that Antler was the first event to affect the region since rifting. Recent Analogs may help visualize the process of formation.



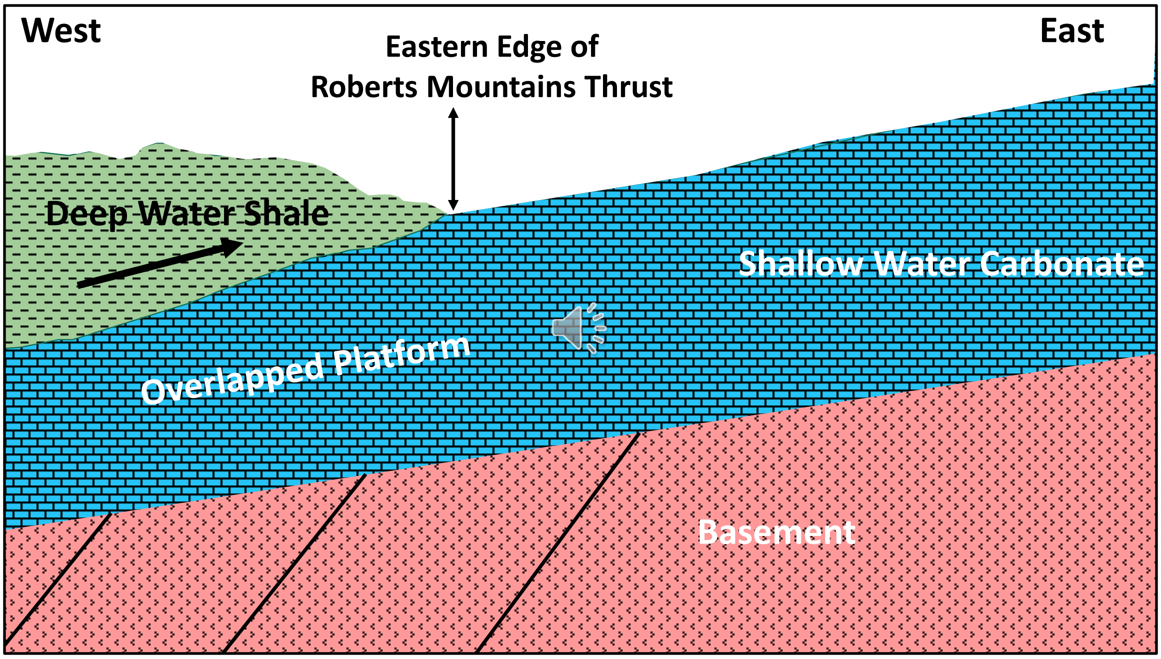
This cross section from Harry Cook shows the Laurentian shelf and slope from the late Precambrian up to the Late Devonian. Fossiliferous limestone grew atop transitional crust at the shelf edge, while restricted platform dolostone accumulated to the east. To the west, Graptolite shale was deposited in deep water on a continental slope.



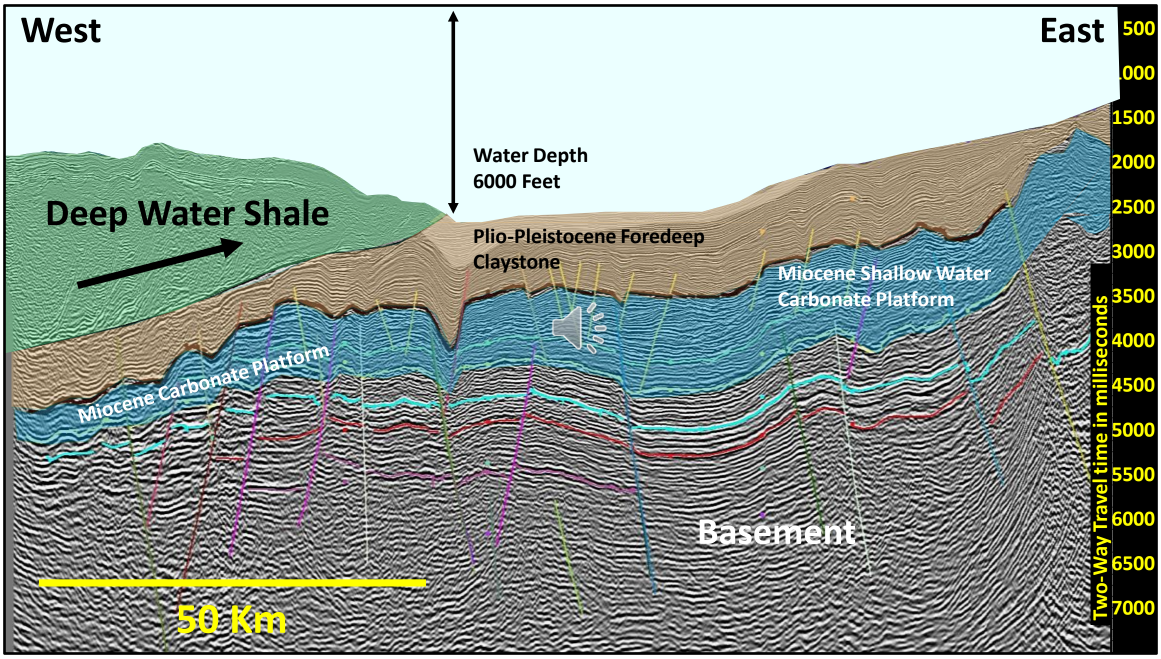
Something happened that pushed slope-shale onto the carbonate platform.



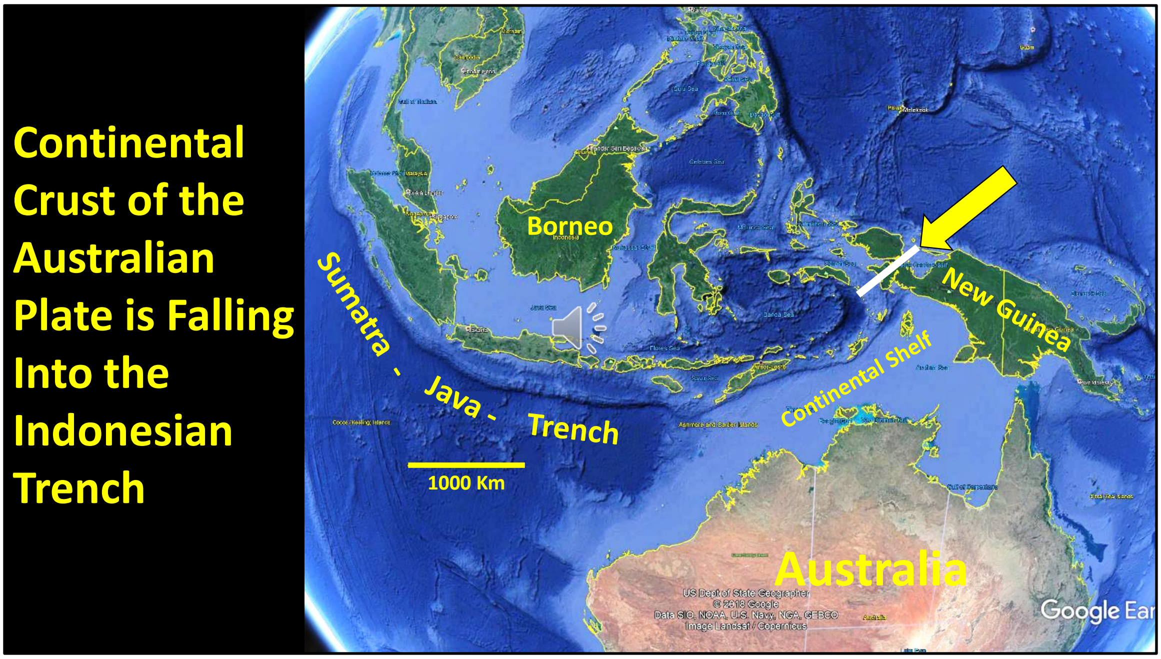
John Stewart's map shows the trace of the Roberts Mountains thrust. The red line is the western extent of the shallow water carbonate platform beneath the thrust. The allochthon overlaps the carbonate platform by about 100 kilometers. A cross section through the overlap would look like this.



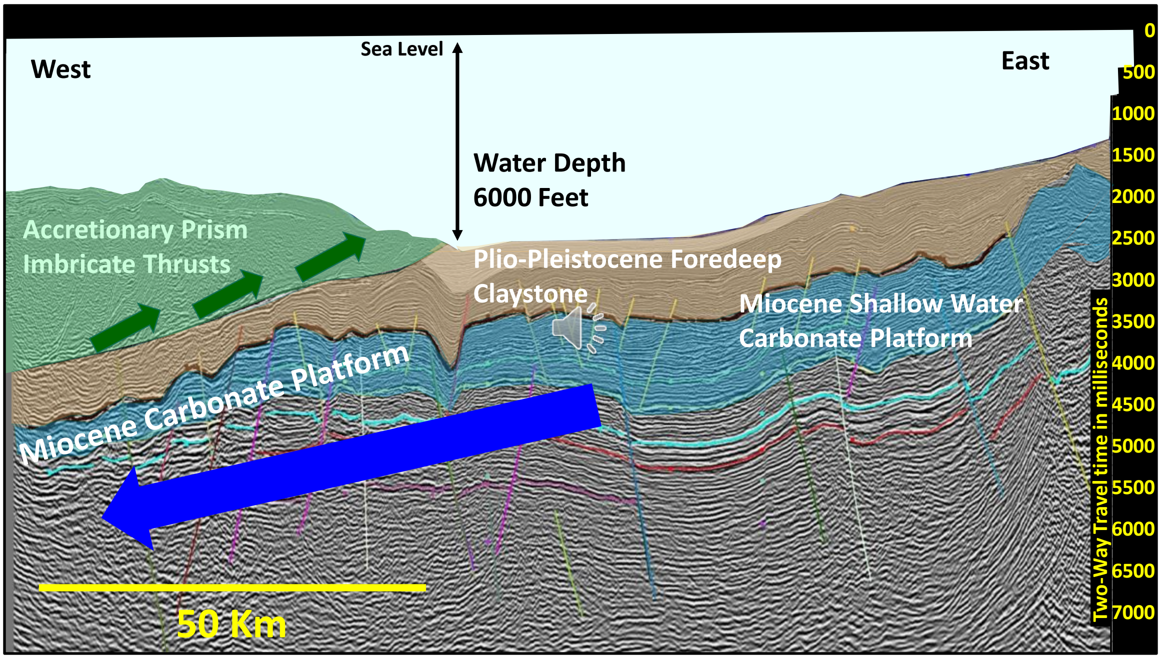
Deepwater shale has obducted on top of a shallow water carbonate platform.



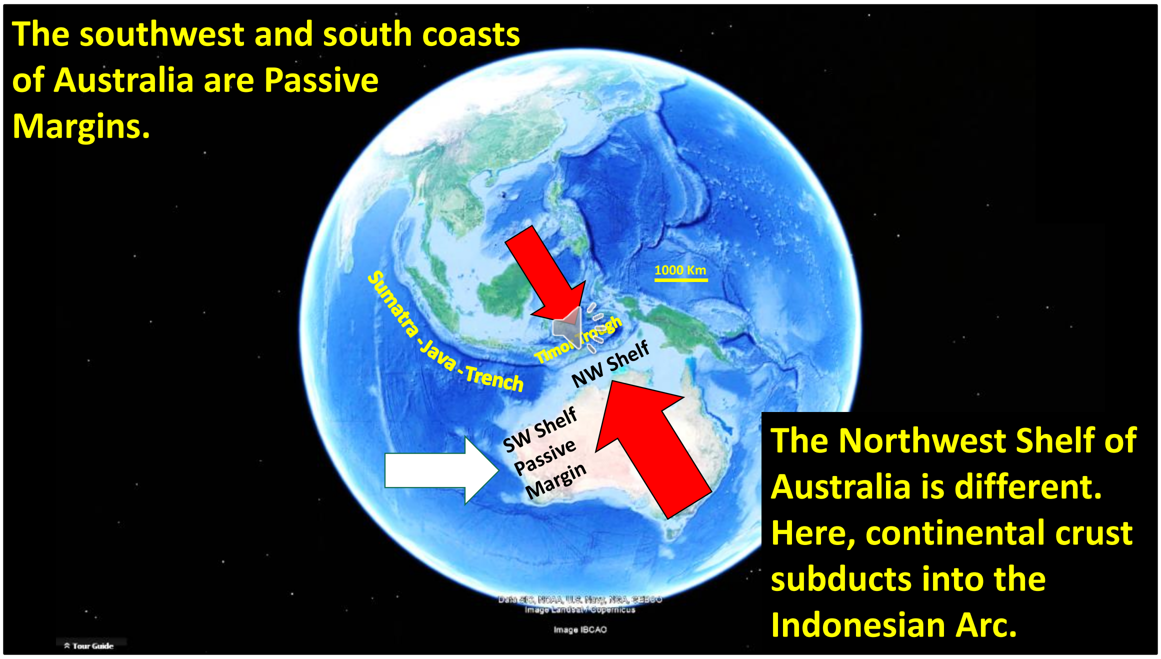
That's why when I looked at this seismic line, I thought I had seen something like it before.



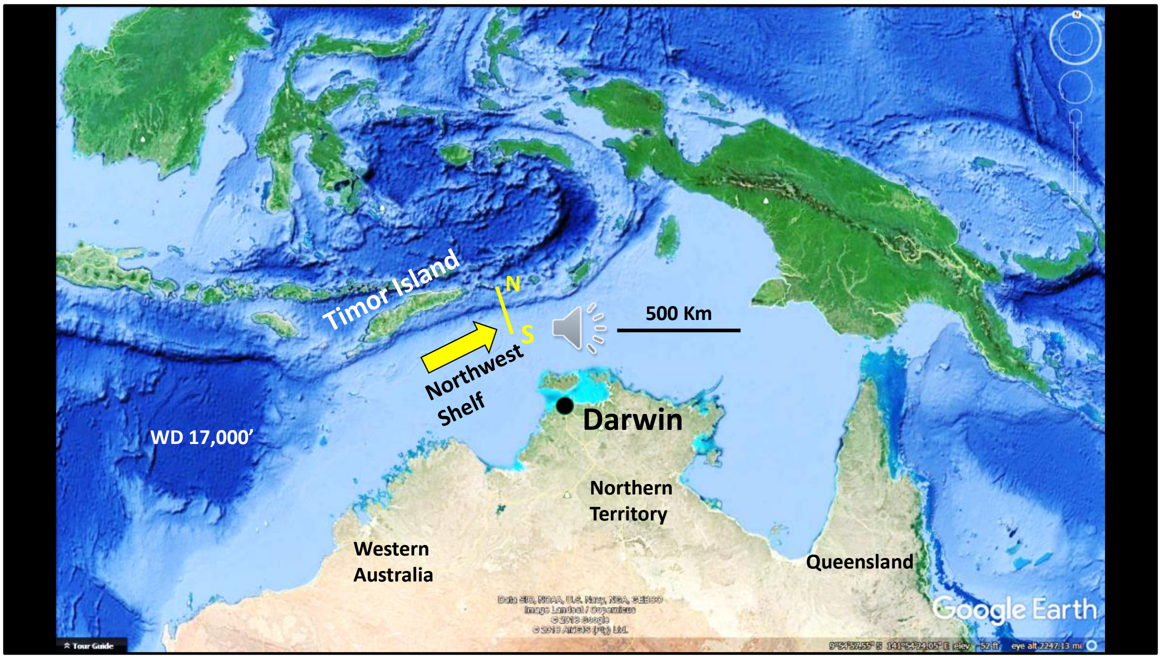
The seismic line is from western New Guinea, where continental crust of the Australian plate is falling into the East Indonesia subduction zone. I worked in Indonesia for several years, after having mapped in the Roberts Mountains some 40 years earlier.



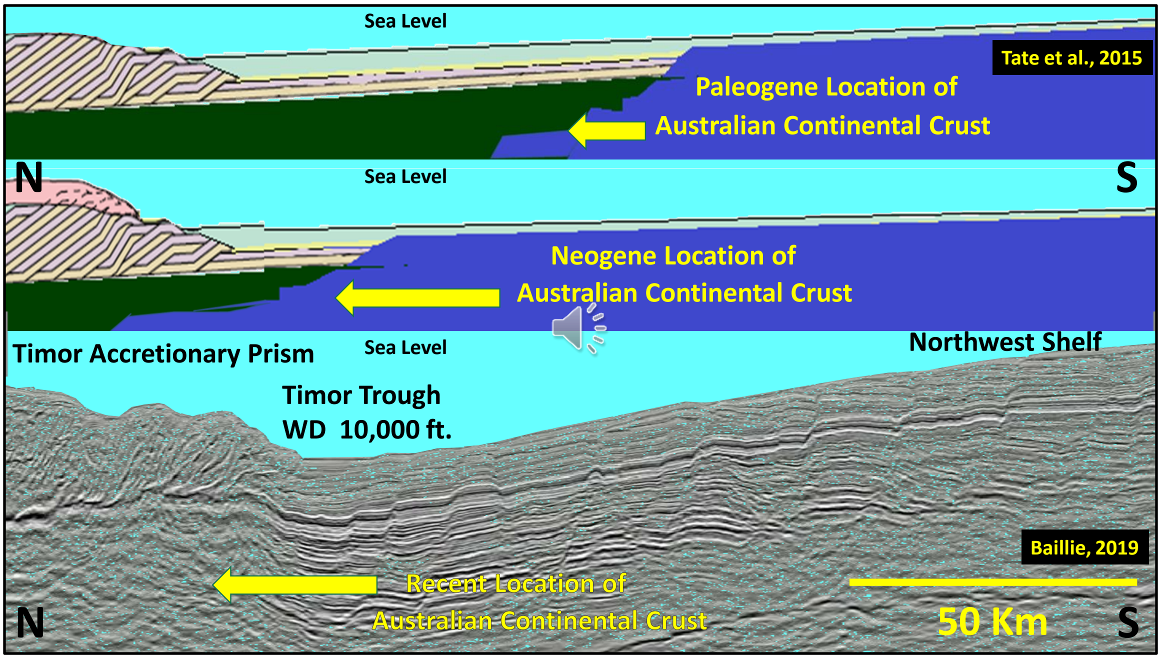
A Miocene carbonate platform is falling into a subduction zone. Sediment scraped off the descending plate forms an accretionary prism above a detachment surface. The carbonate platform grew in shallow water, but as subsidence accelerated through descent into the trench, the platform stopped growing due to drowning, and became overlain by fore-deep claystone.



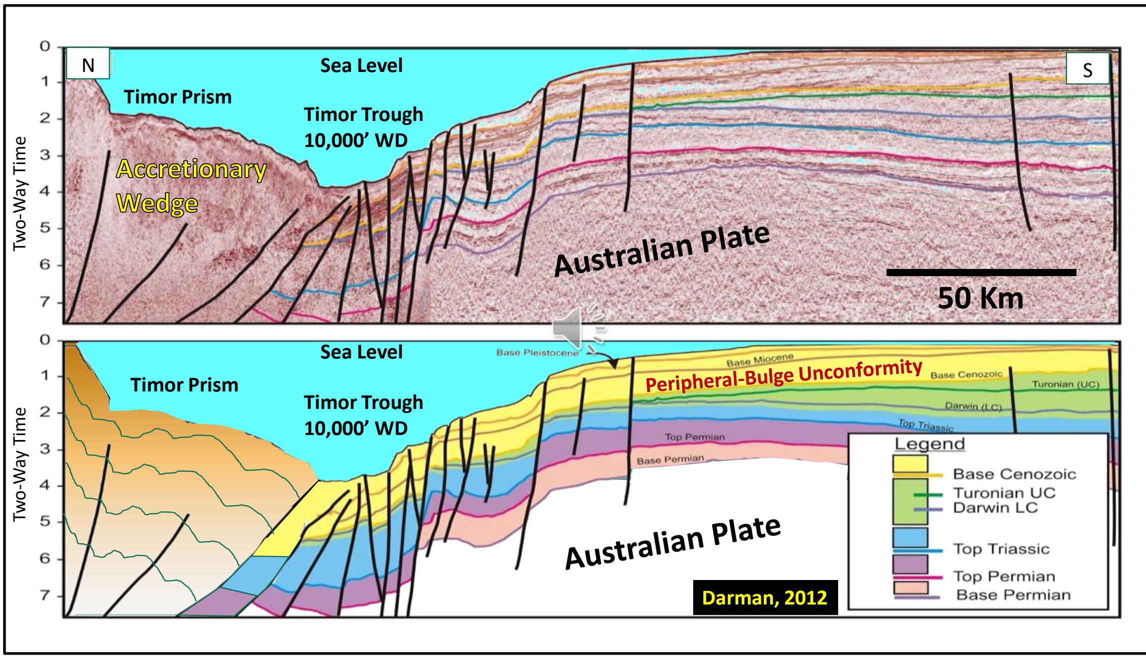
The northwest shelf of Australia is colliding with the Indonesia subduction zone. Australia rifted from Gondwanaland in the Jurassic and has migrated north ever since. At the same time, slab-rollback is moving the Indonesian subduction zone to the south. Simply by coincidence, these plates have encountered one another. This map shows that the south and southwestern coasts of Australia are still passive margins. It is only the Northwest Shelf that has encountered the Timor Trough.



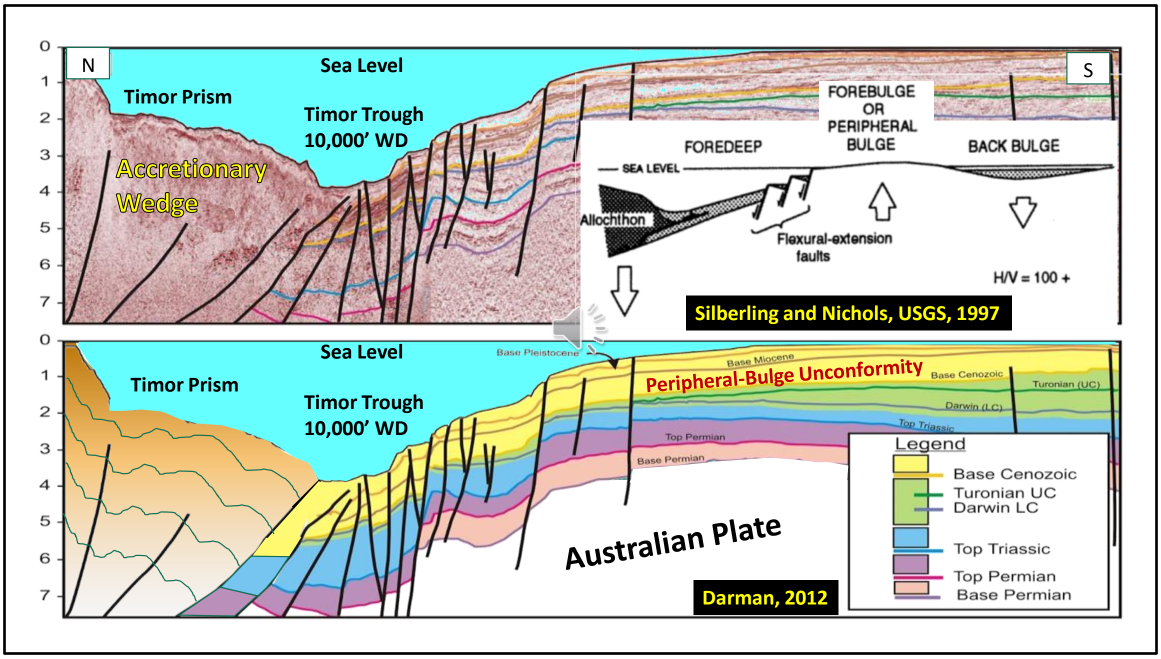
This is the trace of a seismic line that extends from shallow water down to 10,000-foot water depth at the base of the Timor Trough.



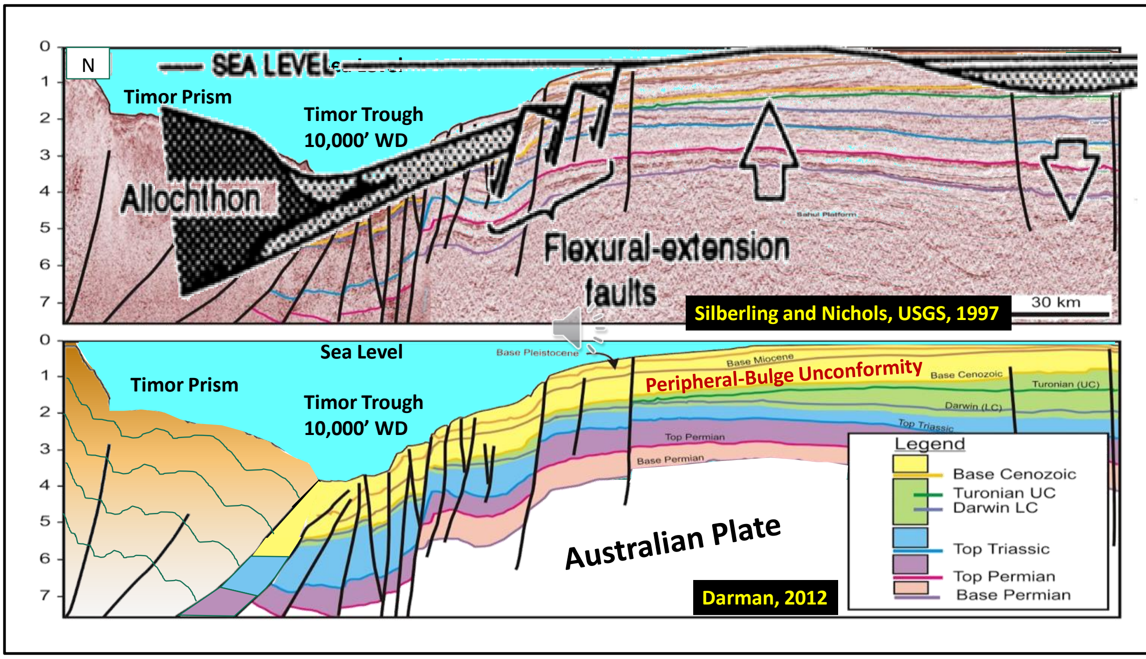
Continental Crust of the Australian Northwest Shelf is falling into the Timor Trough. Deepwater sediment scrapes off the descending plate and piles up into an accretionary prism.



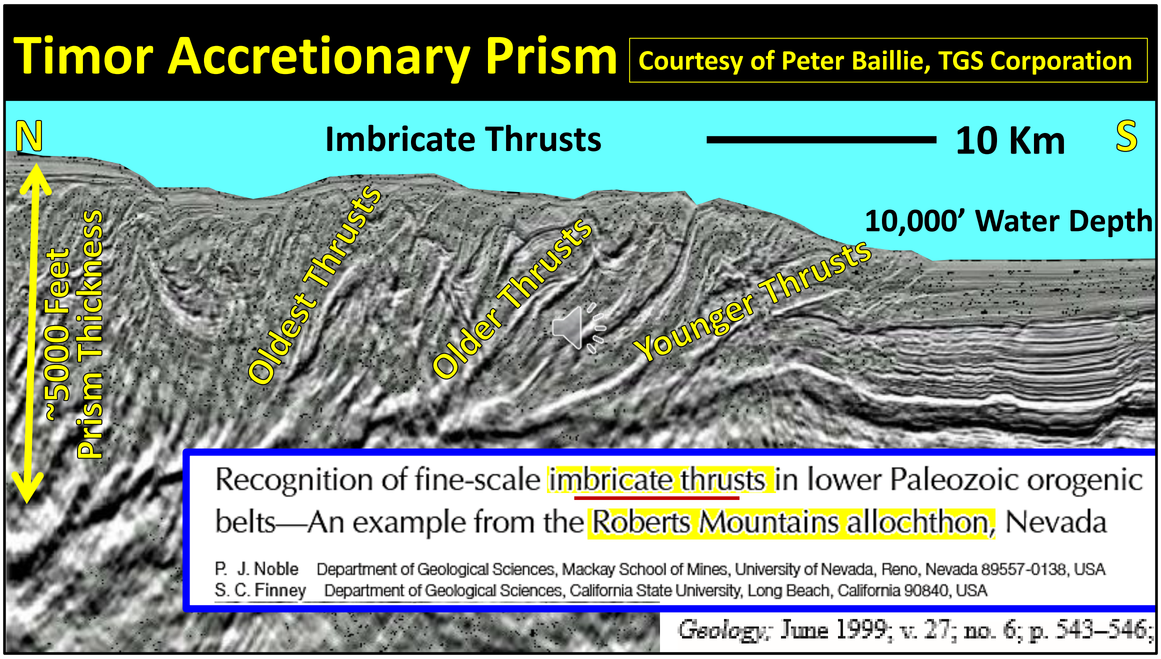
This line stretches for more than 300 kilometers, from a few feet of water on the shelf, to more than 10,000 feet deep at the bottom of the Timor Trough. The Australian plate bends toward the trench, resulting in tension and normal faulting. Toward the shelf, the plate flexes upward into a broad Peripheral Bulge. Shallow water carbonate descends into the trench and is overlain by foredeep mudstone. At the bottom of the trench, the mudstone scrapes off into an accretionary prism that piles up on top of the shallow water carbonate.



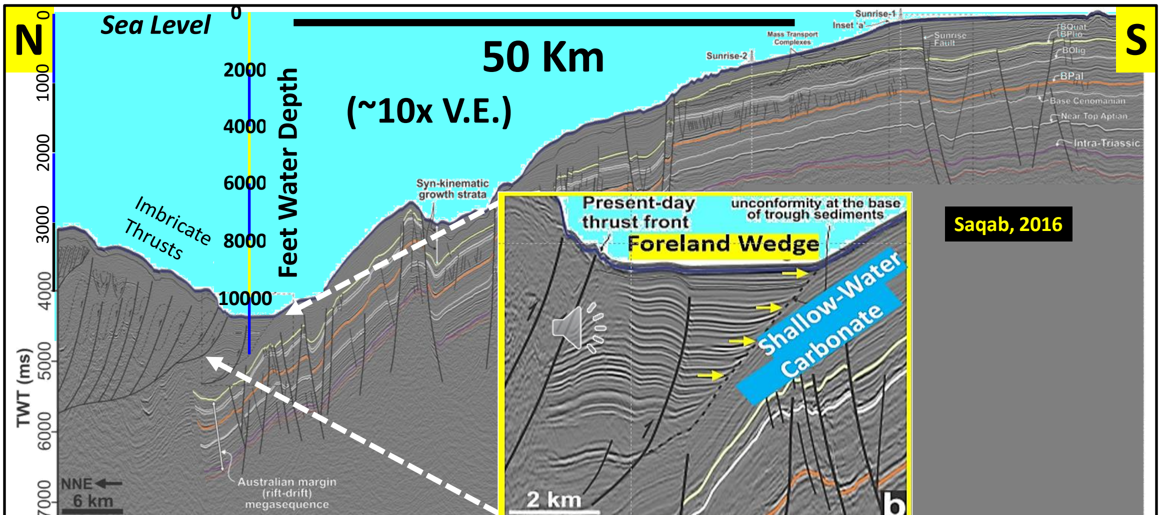
This insert shows a structure section through central Nevada at the time of the Antler Orogeny. You can see by the dates on the sections that Silberling and Nichols could not have seen this seismic line, but their geologic concept based on pure field geology at its finest, compares well to data from the Northwest Shelf.



The Silberling and Nichols interpretation, based on field mapping and biostratigraphy,

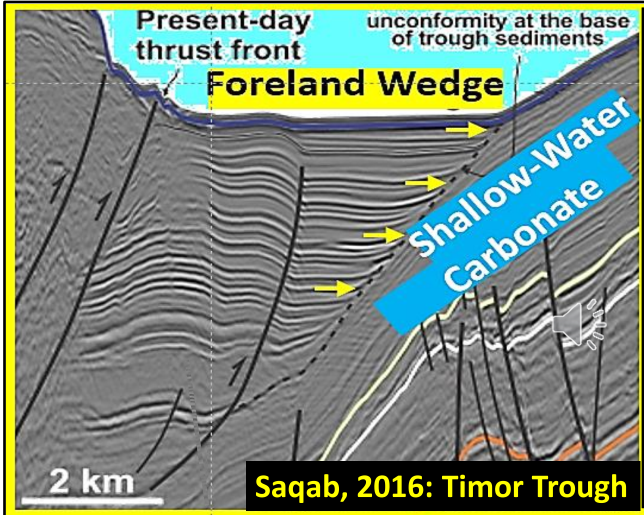


The Timor Accretionary Prism is a sequence of forward-breaking thrusts. The oldest thrust is at the highest part of the prism, while the youngest thrust cuts sediment at the bottom of the trench. Professor Stan Finney's detailed study of the Roberts Mountains thrust concluded that the upper plate was not a single sheet, but rather a collection of imbricate thrusts.



A Foreland Wedge fills the bottom of the trench at Timor, and in the Roberts Mountains.

This is a detail of the Timor Foreland Wedge, which is the fill at the very bottom of the trench. To the left is the first imbricate of the accretionary prism. To the right is an angular unconformity where flat-lying trench-fill sediment onlaps against the subducting slab.



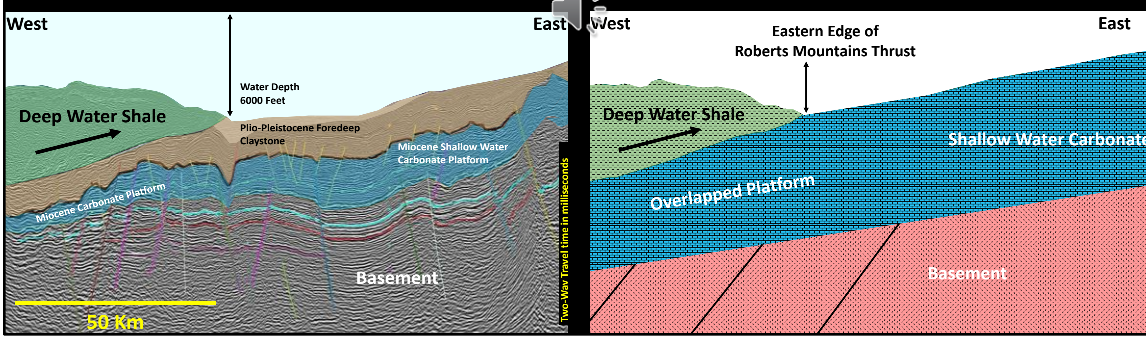
Murphy, Power, and Johnson, 1984: Mississippian Webb Formation "accumulated at the toe of the moving Roberts Mountains allochthon".

Black shale and chert overlie an angular unconformity atop Devonian Limestone.

Analog for Webb Formation at the bottom of the Roberts Trench.

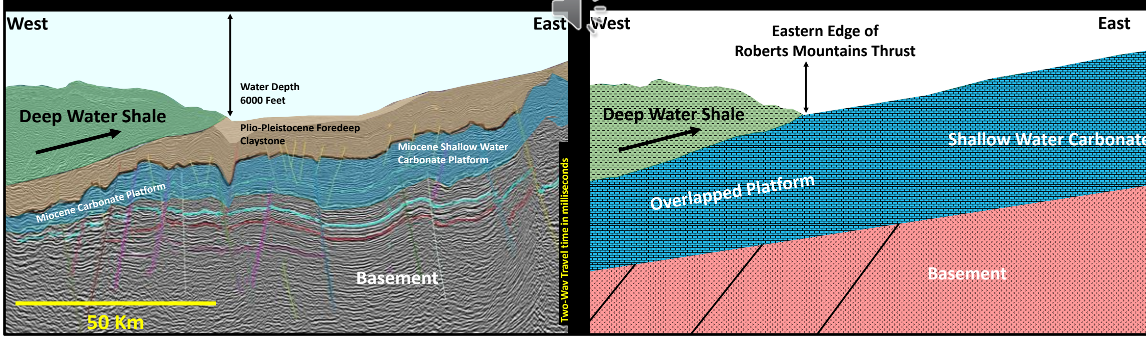
In the Roberts Mountains, the Mississippian Webb Formation forms a foreland wedge bounded by the first imbricate of the Roberts Mountains Thrust to the West, and onlap against Upper Devonian Limestone to the East.

- **What triggered the Antler Event?**
- **West-dipping subduction of the Laurentian passive-margin carbonate platform into an ocean trench can explain emplacement of deepwater claystone on top of shallow-water carbonate sediment.**

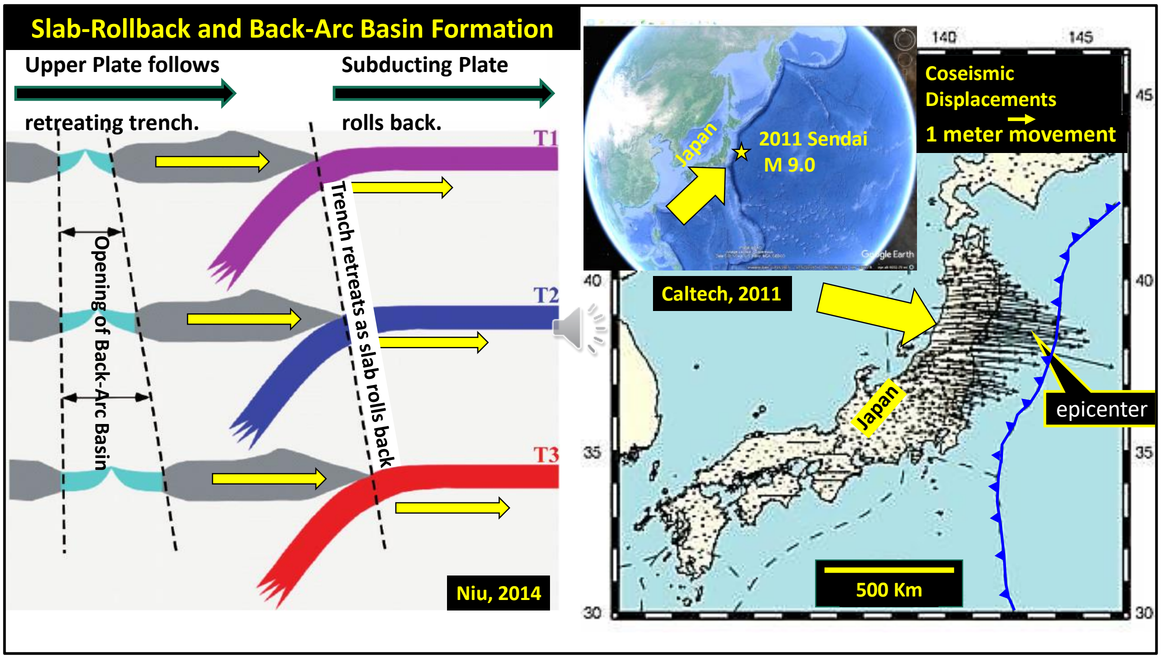


What triggered the Antler Event? Continental subduction can emplace deep-water shale on top of shallow water carbonate; with geometry and scale comparable to the Roberts Mountains thrust.

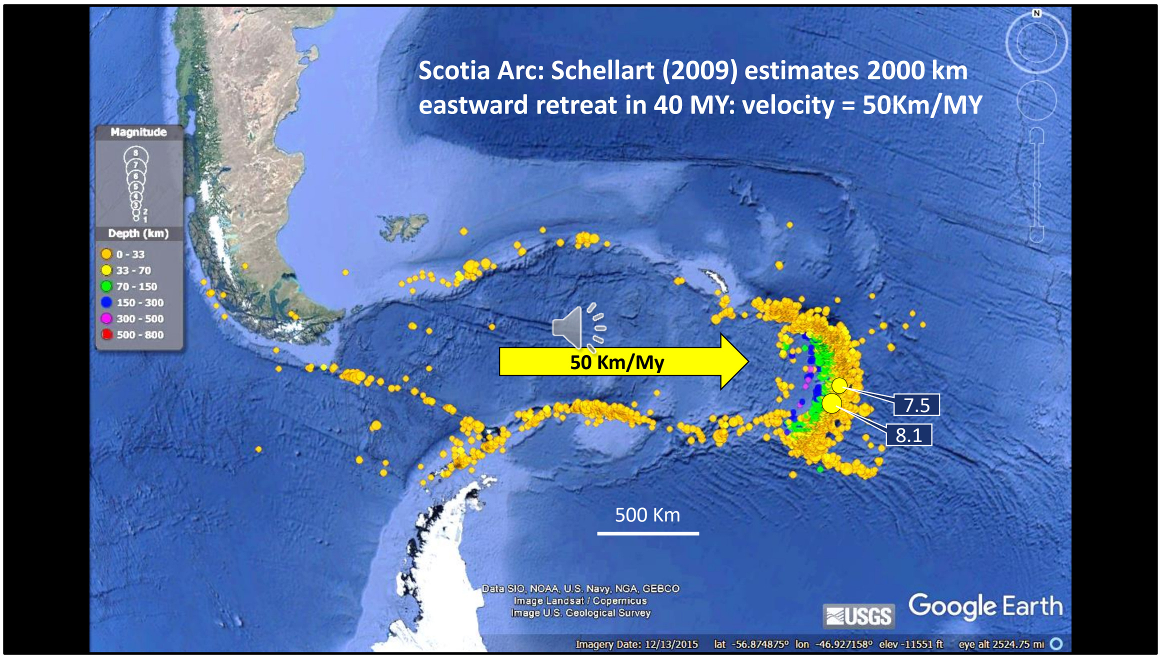
How did a trench arrive on the scene after ~ 300 MY of Passive Margin conditions?



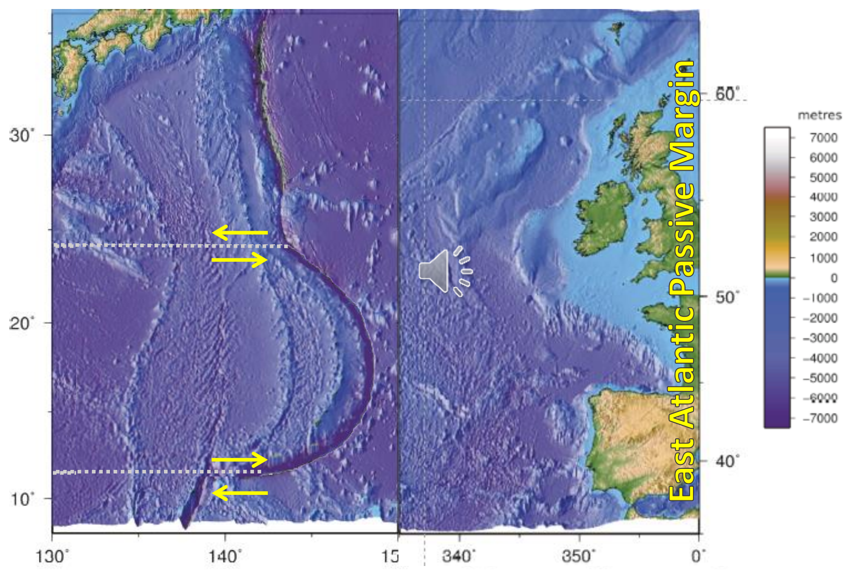
But if it was a subduction zone, how did it get to the Laurentian shelf?



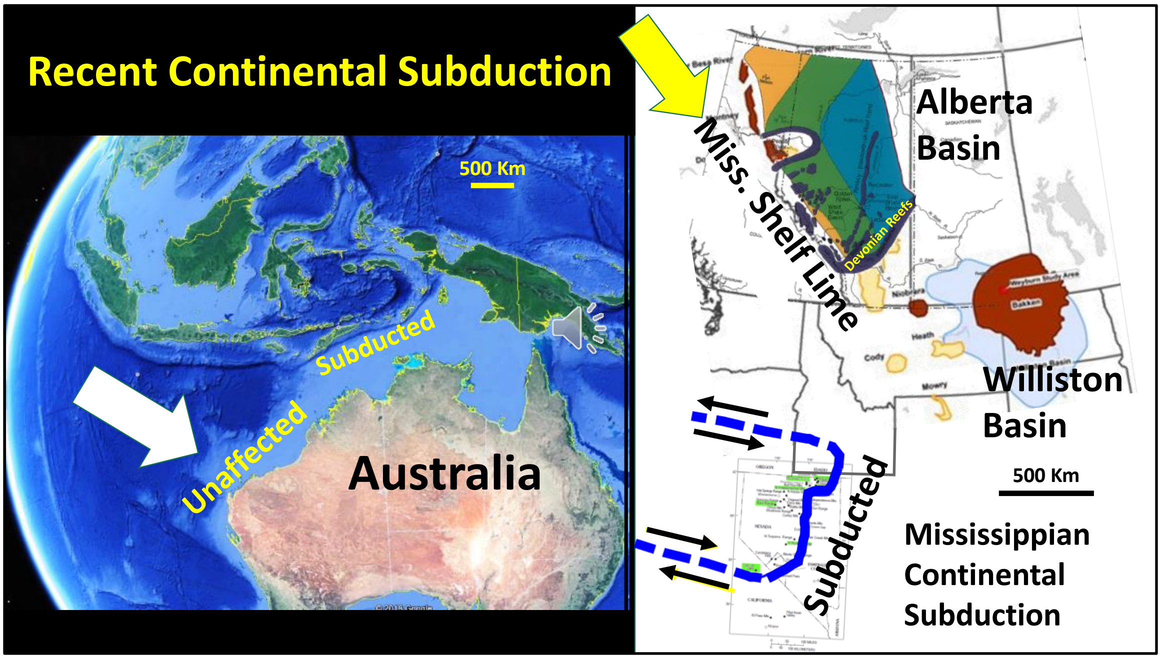
Ocean Trenches migrate through the process of Slab Rollback. The hinge line of the subducting plate moves backward away from the trench. GPS ground motion measurements following the magnitude 9 Sendai Earthquake show that the hinge line of the descending slab moved eastward, and at the same time the upper plate moved eastward instantaneously up to 10 meters to take up the space left by the slab-rollback process.



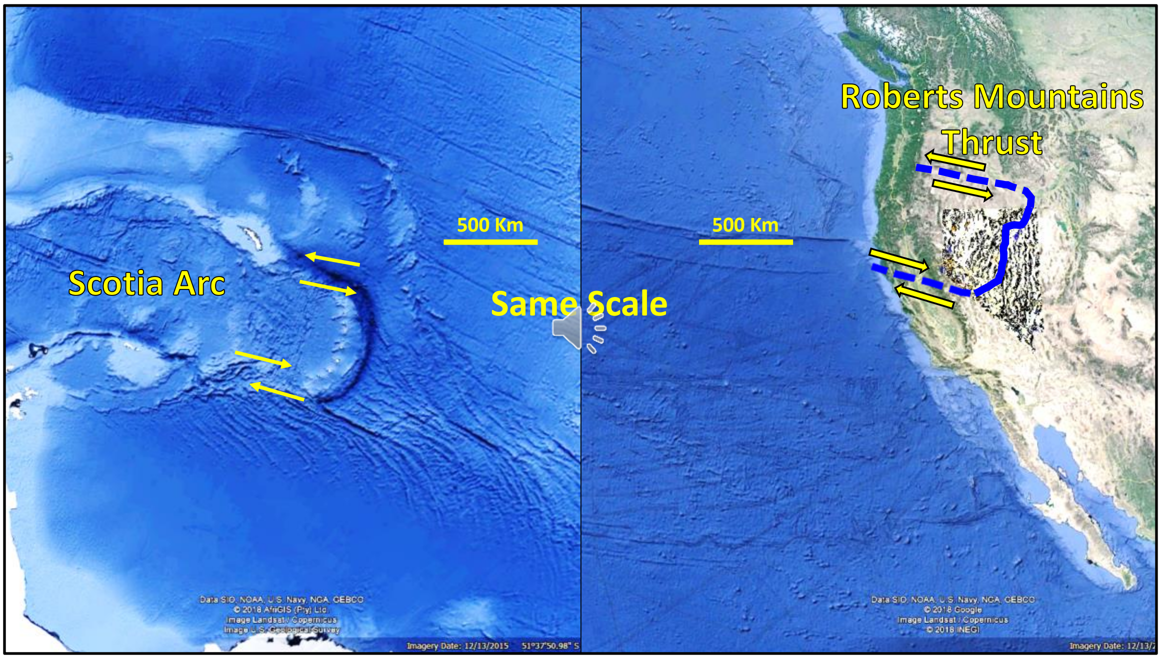
Ocean trenches roll across ocean crust at plate tectonic rates. Estimates from the Scotia Arc indicate 50 km of migration per million years. At this rate, a trench could have migrated thousands of kilometers over the 300-million-year history of the Laurentian passive margin.



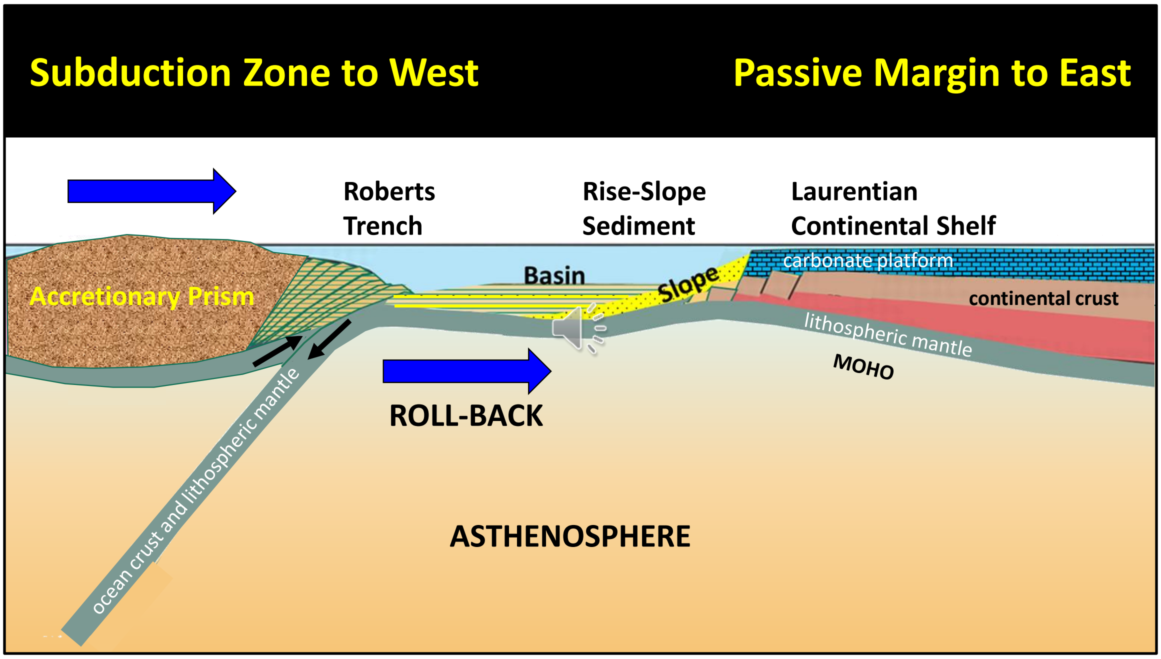
How could an arc move toward a passive margin? Slab rollback provides an explanation.



Continental subduction takes place where a passive margin encounters a trench. But subduction zones do not go on forever. They may terminate at transform faults, or they may curve away from the edge of a passive margin. In the case of Australia, the Indonesian subduction zone curves to the west and leaves the southwest shelf unaffected. The map on the right shows that the Alberta and Williston Basins had continuous carbonate growth from the Devonian up through the Carboniferous. These areas were not affected by the Antler Orogeny. The Roberts Mountains trench may have terminated at Transform Faults to the south of those basins.

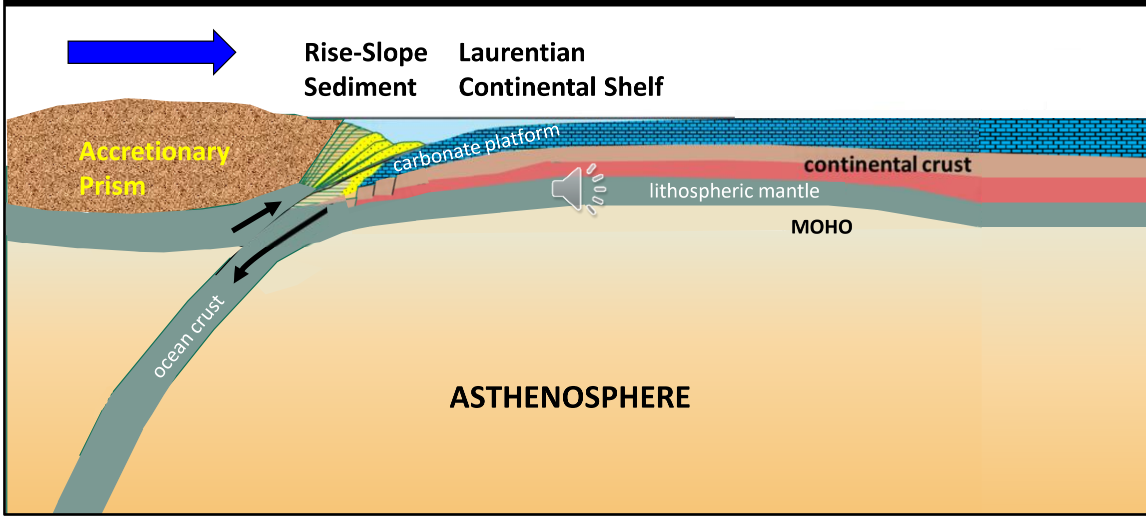


A comparison of the Roberts Mountains Thrust and the Scotia Arc at the same scale. Though their precise location isn't known, there must be transforms at either end of the Roberts Thrust.



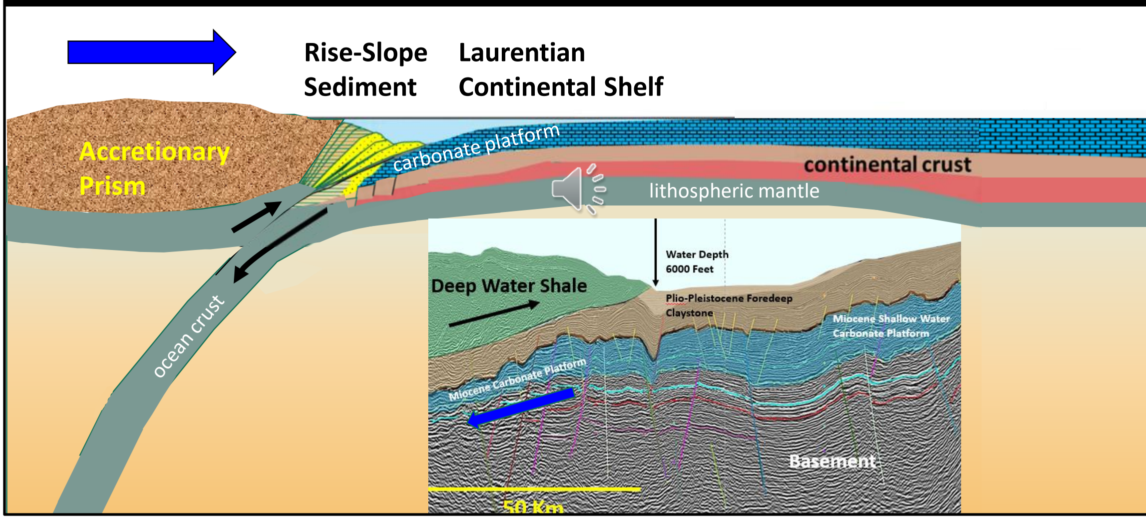
Slab rollback causes a west-dipping subduction zone to approach the Laurentian shelf. Sediments of the slope and basin would contain fossils transported from the shelf.

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.



The shallow water carbonate platform descends into the trench, and slides below the accretionary prism. By this time, a stack of imbricately thrusted deep-water sediment is emplaced atop shallow-water carbonate platform sediment. Gravity drives the process; nothing is really thrusted up on top of the platform.

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.

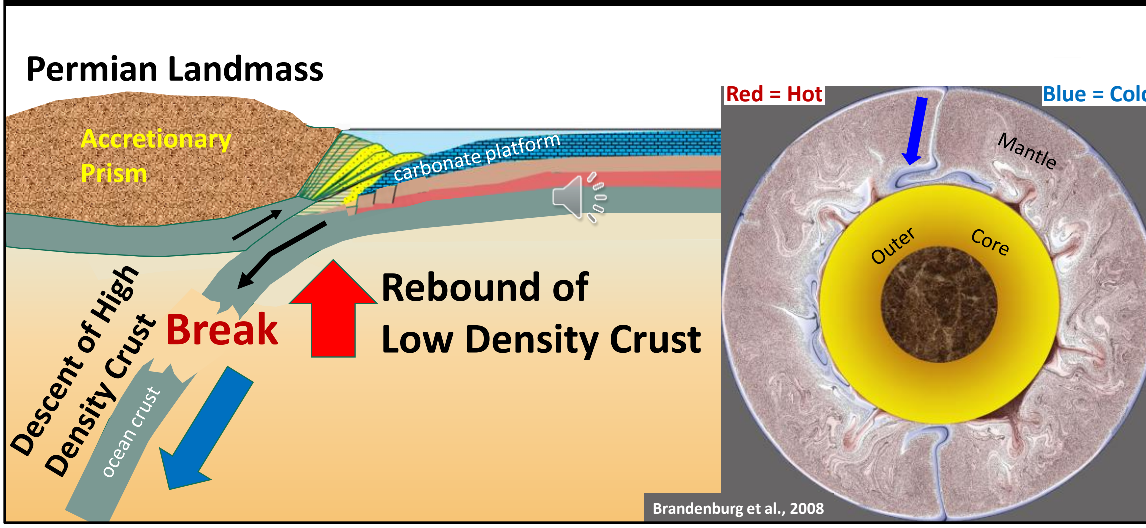


This process is driven by gravity and is active in Recent time.

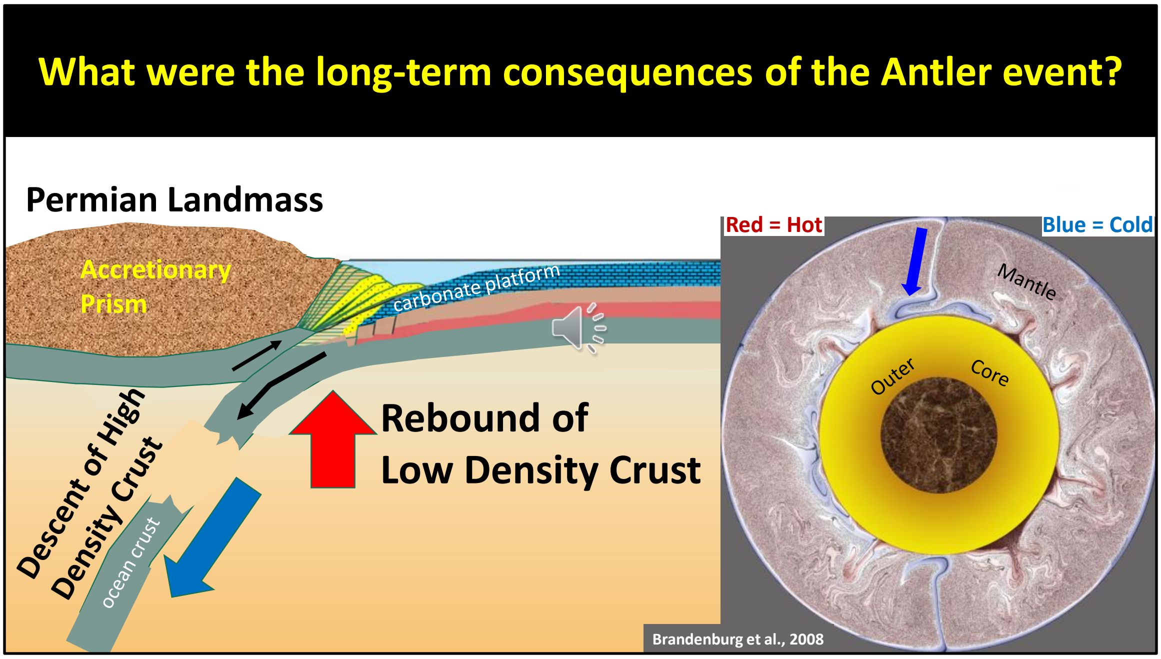
Permian Carbonates in Simpson Park Range contain large fusilinids and abundant green chert clasts eroded from upper plate. This is analogous to subaerially exposed Timor and Barbados accretionary prisms.

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

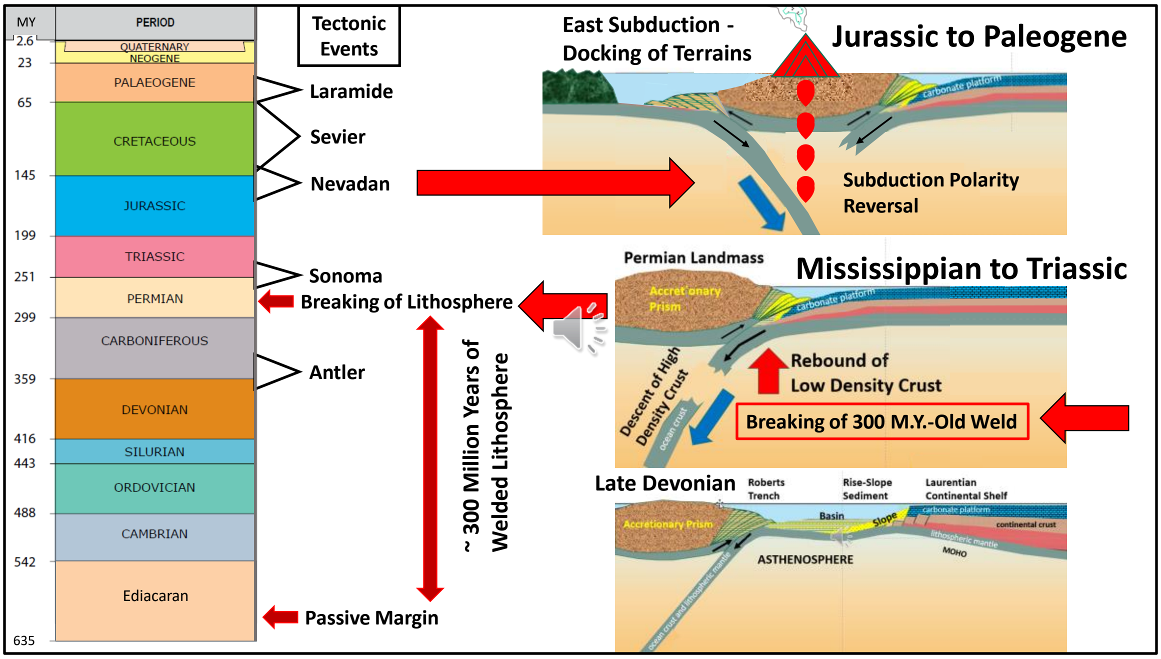
Deepwater rise and slope sediments containing fossils from the shelf are now emplaced atop the shallow water carbonate platform. Basalt slab descends into mantle. Accretionary prism rebounds and sheds rock-fragment “molasse”.

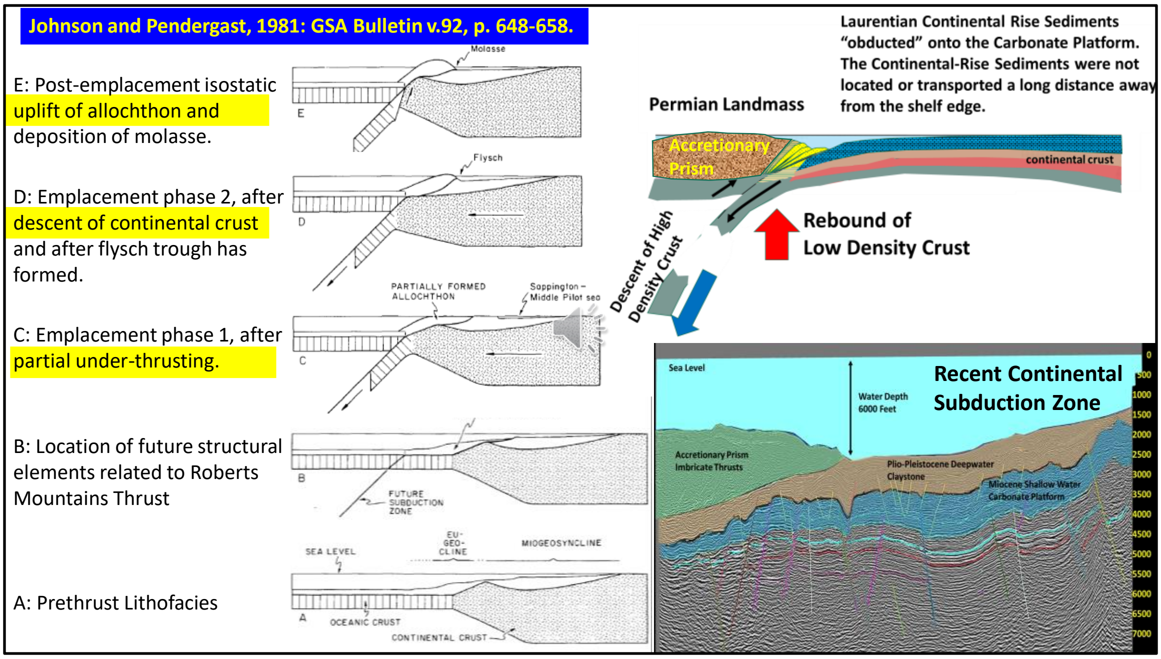


The low density of continental crust prevents it from subducting into the mantle. Eventually it sticks, and the basalt part of the plate breaks-off and continues descent. Then, the continental part rebounds to some degree, accentuating the uplift of the Accretionary prism. In the case of Timor Island in Indonesia, the exposed landmass reaches 1000 meters elevation. The figure on the right is a computer model based on seismic tomography that shows cold dense subducted lithosphere descending to the base of the mantle.

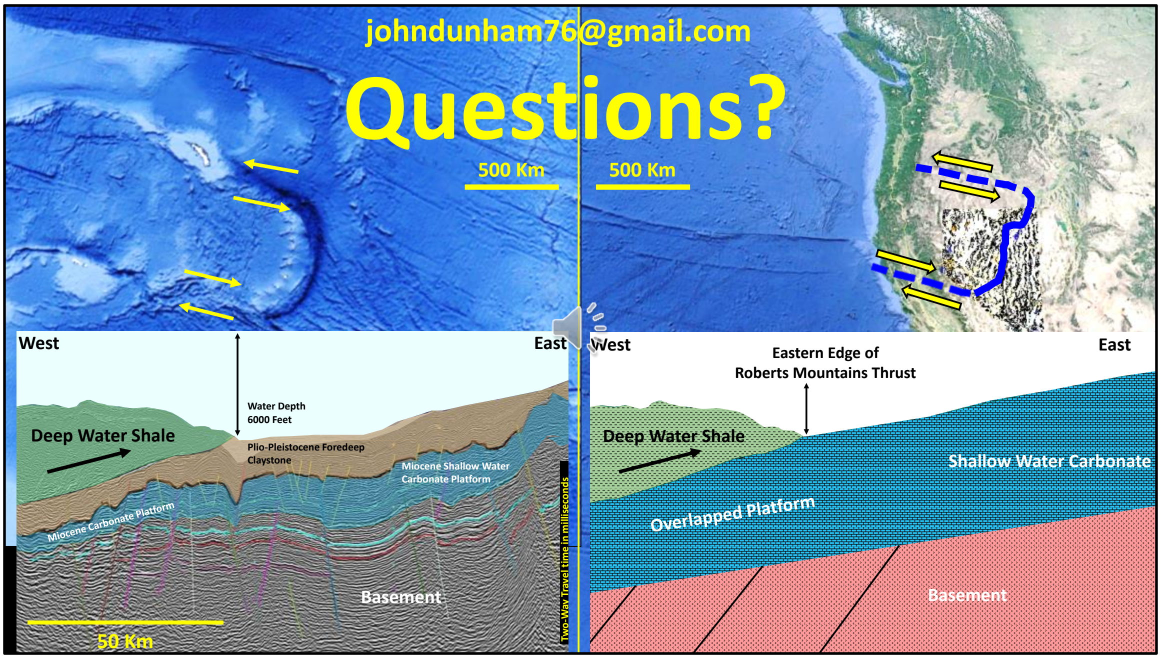


What were the long-term consequences of the Antler event?

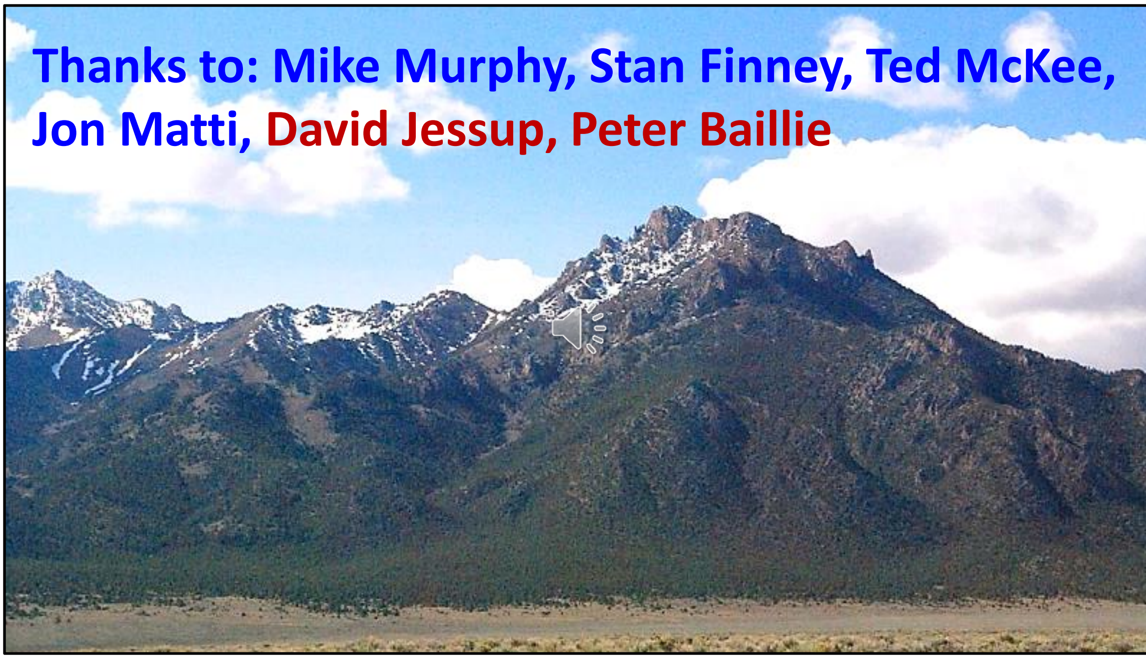

MY
PERIOD
2.6
QUATERNARY
NEOGENE
23
PALAEOGENE
65
CRETACEOUS
145
JURASSIC
199
TRIASSIC
251
PERMIAN
299
CARBONIFEROUS
359
DEVONIAN
416
SILURIAN
443
ORDOVICIAN
488
CAMBRIAN
542
Ediacaran
635
Tectonic Events
Laramide
Sevier
Nevadan
Sonoma
Breaking of Lithosphere
Antler
~ 300 Million Years of Welded Lithosphere
Passive Margin
East Subduction - Docking of Terrains
Jurassic to Paleogene
carbonate platform
Subduction Polarity Reversal
Permian Landmass
Mississippian to Triassic
Accretionary Prism
carbonate platform
Descent of High Density Crust
ocean crust
Rebound of Low Density Crust
Breaking of 300 M.Y.-Old Weld
Late Devonian
Roberts Trench
Rise-Slope Sediment
Laurentian Continental Shelf
carbonate platform
Accretionary Prism
Basin
Slope
continental crust
lithospheric mantle
MOHO
ASTHENOSPHERE
ocean crust and lithospheric mantle



In summary, Jess Johnson envisioned this in 1981. West-dipping subduction caused the overlap of deepwater shale atop shallow-water carbonate. Slab-rollback drove the migration of the subduction zone. Recent analogs make it easier to see this process.



In anticipation of questions, I'll show the following backup slides.

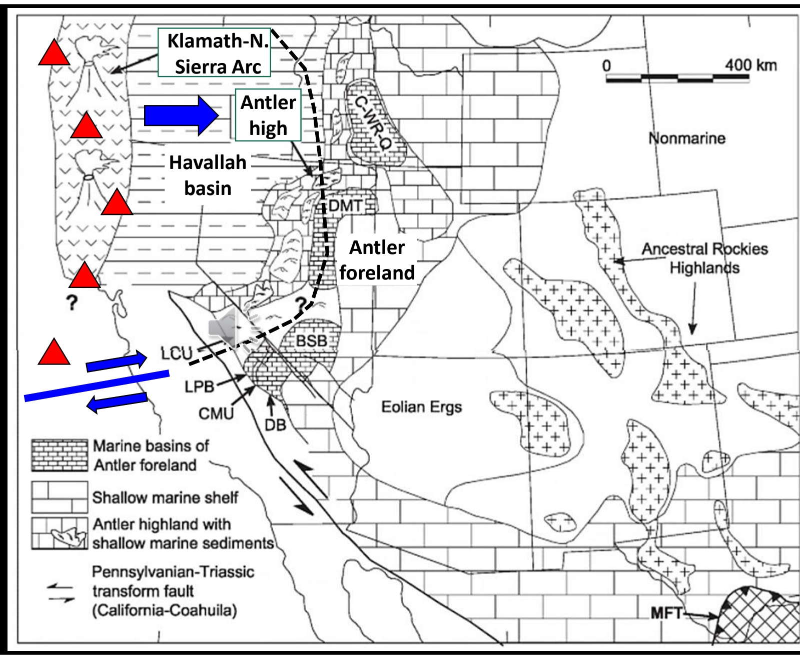


- This backup slide anticipates a question about what it would take to turn this presentation into a paper. To do that, I would ask the names in blue to supply field observations and biostratigraphic data as co-authors, and the names in red to provide additional geophysical data as co-authors.

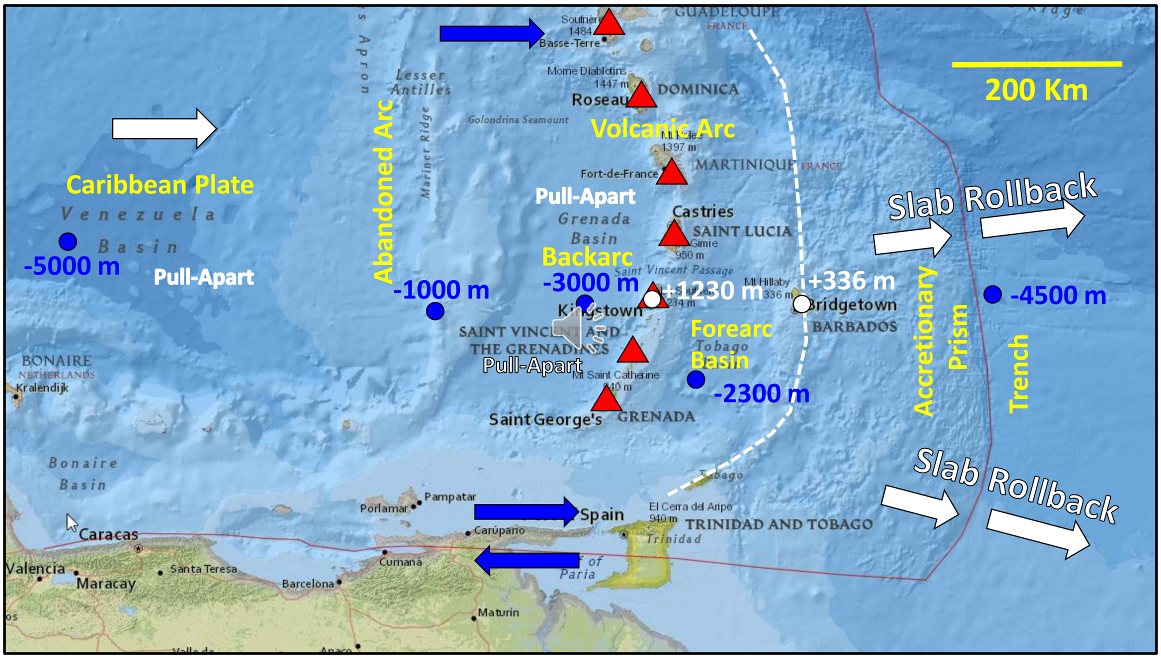
Sonoma Orogeny – A Reassessment

Snyder, W.S., Brueckner, H.K., Northrup, C.J., 2019

SEPM Sp. Pub. 113



This slide anticipates a question about a recent publication on the Sonoma Orogeny that affected the Antler Forearc Basin. Compare this map to the following analogy from the Caribbean Plate.



The Caribbean Plate migrates at a rate of about 30 km per million years through the process of slab rollback. A foreland wedge fills the bottom of the trench, an accretionary prism rises to above sea level at Barbados Island. The topographic low between the accretionary prism and the volcanic arc is the forearc basin, which continuously deforms as the upper plate moves to the east. Behind the arc are spreading centers that pull apart as the upper plate jumps to the east, leaving behind pullapart basins and abandoned arcs. The Antler orogeny occurred when the laurentian margin fell into the trench. The Sonoma orogeny occurred as the momentum of the converging plates deformed the forearc basin.

References Cited on Slides:

Reference
Baillie, P., Carter, P., and Duran, P.M., 2019, Evolution and Plays of the Banda Arc: AAPG Search and Discovery Article #11245, DOI:10.1306/11245Baillie2019, http://www.searchanddiscovery.com/documents/2019/11245baillie/ndx_baillie.pdf
Brandenburg, J.P., Hauri, E., vanKeken, P., and Ballentine, C., 2008, A multiple-system study of the geochemical eolution of the mantle with force-balanced plates and thermochemical effects: Earth and Planetary Science Letters v. 276, p. 1-13, doi:10.1016/j.epsl.2008.08.027 See also: Plank, T., and vanKeken, P., 2008, The ups and downs of sediments: Nature Geoscience, v. 1, p. 17-18. https://doi.org/10.1038/ngeo.2007.68
Caltech - JPL ARIA group, 2011: http://www.tectonics.caltech.edu/slip_history/2011_taiheiyo-oki/
Cook, H.E., 1983, Great Basin Paleozoic Carbonate Platform: facies, facies transitions, depositinal models, platform architecture, seuence stratigraphy, and predictive mineral host models: USGS Open-File Report 2004-1078, 129 p.
Darman, H., 2012, Timor Sea - Chapter 11 of Seismic Atlas of SE Asian Basins: http://geoseismic-seasia.blogspot.com/search/label/11%20Timor%20Sea
Ingersoll, 2008, Subduction-related sedimentary basins of the USA Cordillera: in Miall, A.D. (ed.), the Sedimentary Basins of the United States and Canada, Elsevier, p. 395-428, doi: 10.1016/S1874-5997(08)00011-7
Johnson, J.G., and Pendergast, A., 1981, Timing and mode of emplacement of the Roberts Mountains allochthon, Antler orogeny: Geological Society of America Bulletin, v. 92, p. 648-658.
Ligi et al., 2012, Birth of an ocean in the Red Sea: initial pangs: Geochemistry Geophysics Geosystems, v. 13, p. 1-29, doi:10.1029/2012GC004155
Murphy, M.A., Power, J.D., and Johnson, J.G., 1984, Evidence for Late Devonian movement within the Roberts Mountains allochthon, Roberts Mountains, Nevada: Geology, v. 12, p. 20-23.
Niu, Y., 2014, Geological understanding of plate tectonics: Basic concepts, illustrations, examples and new perspectives: Global Tectonics and Metallogeny v. 10, p. 23-46, DOI: 10.1127/gtm/2014/0009, https://dro.dur.ac.uk/15761/1/15761.pdf?DDD15+dgl0yn+d700tmt
Noble, P.J., and Finney, S.C., 1999, Recognition of fine-scale imbricate thrusts in lower Paleozoic orogenic belts - an example from the Roberts Mountains allochthon, Nevada: Geology, v. 27, no. 6, p. 543-546.
Schellart, W.P., 2010, Evolution of subduction zone curvature and its dependence on the trench velocity and the slab to upper mantle viscosity ratio: Journal of Geophysical Research vol. 115, B11406, p 1-18, doi:10.1029/2009JB006643
Silberling, N.J., Nichols, K.M., Trexler, J.H., Jewell, P.W., and Crosbie, R.A., 1997, Overview of Mississippian Depositional and Paleotectonic History of the Antler Foreland, Eastern Nevada and Western Utah: BYU Studies in Geology v. 42, part 1, p. 161-196.
Speed, R.C., and Sleep, N.H., 1982, Antler orogeny and forland basin: a model: Geological Society of America Bulletin, v. 93, p. 815-828.
Stewart, 1980, The Geology of Nevada - a discussion to accompany the Geologic Map of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.
Tate, G.W., McQuarrie, N., vanHinsbergen, J., Bakker, R., Harris, R., and Jiang, H., 2015, Australia going down under; quantifyng continental subduction during arc-continent accretion in Timor-Leste: Geosphere, v. 11, no. 6, p. 1-24, doi:10.1130/GES01144.1
Torsvik, T.H., 2003, The Rodinia jigsaw puzzle: Science, V. 300 p. 1379-1381, doi.10.1126/science.1083469

References listed above