

# **Arc-Continent Collision: A Comparison of the SE Caribbean and Taiwan-Ryukyu Margins\***

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## **Abstract**

Subduction of the combined west-moving North and South American oceanic plates beneath the east-moving Caribbean Plate with consequent development of the Lesser Antilles Arc has long been accepted as a model for collision between two oceanic plates, after Cox and Hart (1986). Earthquake evidence (presented in the form of seismic tomography) supports this model but, additionally, supports subduction of the Caribbean Plate beneath the continental part of the South American Plate, after Pindell and Kennan (2007).

Since the South American Plate is comprised of both continental and oceanic crust which joins at a stable continent-ocean boundary (Guyana COB), it is difficult to reconcile how the Caribbean Plate can both override and be subducted beneath what appears to be the same plate margin. Comparison with the better understood and documented Taiwan-Ryukyu margin provides a model for this arc-continent collision which has been the underlying driver for a world-class petroleum system: *Oil and Gas Journal* reports 79.7 billion barrels of proven conventional oil reserves in Venezuela alone (includes Maracaibo Basin) with as much as 270 billion extra-heavy oil and bitumen in the Orinoco Tar Belt. Crustal loading in advance of the collision creates major accommodation space for sedimentation (reservoir and seal development); it pushes former passive margin source rocks down into the generating window (source maturation below reservoir), and allows space for subsequent tectonic stacking of the recently deposited reservoir and seal sediments (trap development).

While at first the Taiwan-Ryukyu margin may not appear to be a close analogue for the SE Caribbean margin, closer examination reveals a strong similarity. The WNW-moving Philippine Sea Plate can be considered equivalent to the Caribbean Plate while the Eurasian Plate can be considered equivalent to the South American Plate. The Tainan Basin, where loading is currently occurring in advance of collision, can be considered equivalent to the Columbus Basin. Extensive study of the Taiwan-Ryukyu margin using both

surface geology and seismic tomography reveals that the oceanic part of the Eurasian Plate is being subducted beneath the Philippine Sea plate along the Luzon Arc. At the same time, the Philippine Sea Plate is being subducted beneath the continental part of the Eurasian Plate along the Ryukyu Arc.

Suppe (1984) and, more recently Clift et al. (2003) and Sibuet et al. (2004), have developed a workable model for “continuous arc accretion” where a progressive tear of the crust follows the line of weakness at the continent-ocean boundary (COB) to facilitate the subduction reversal. When viewed from an appropriate geographic perspective, a direct comparison of the two margins can be made. It can be seen that the same abrupt transition between a compressive to tensile regime can be made in both locations. The transition occurs along a zone which Suppe termed the plane of subduction flip.

Comprehension of the Taiwan-Ryukyu arc-continent collision leads to an improved understanding of the SE Caribbean margin. A strong genetic similarity is apparent between the Columbus and Tainan Basins (crustal loading in front of the advancing tectonic front), between the East Venezuela-Trinidad Thrust Belt and Taiwan’s Western Foothills (tectonic stacking of recently deposited foreland sediments), and between the Cariaco Trough and S. Okinawa Basin (back-arc rifting in the lee of the advancing arc-continent collision).

Why then has one arc-continent collision given rise to a world-class petroleum system whereas the other has yet to realize major potential? It is suggested that the rate of convergence between plates controls the rate at which the collision zone is laterally propagated. This in turn controls the depth and extent of crustal loading in advance of collision and hence the volume of accommodation space available for reservoir deposition as well as the rate and depth of burial of former passive margin sediments for source rock maturation. The Taiwan-Ryukyu collision, efficient with a closing plate convergence of 82mm/year and lateral propagation of 95 mm/year, leaves little time or space (150,000 km<sup>2</sup>) to develop a major petroleum system. The more laborious SE Caribbean collision, with a closing plate convergence of <40 mm/year and similar lateral propagation rate, allows considerably more time for the petroleum system to develop as well as providing a greater area for it to cover (300,000 km<sup>2</sup>).

## References

Clift, P.D., H. Schouten, and A.E. Draut, 2003, A general model of arc-continent collision and subduction polarity reversal from Taiwan and the Irish Caledonides, *in* Intra-Oceanic Subduction Systems: Tectonic and Magmatic Processes, R.D. Larter and P.T. Leat eds., Geological Society (London), Special Publication No. 219, p. 81-98.

Cox, A. and R. B. Hart, 1986, Plate Tectonics: How it works: Blackwell, 392 p.

Gibson, Richard G., Leon I.P. Dzou, and David F. Greeley, 2004, Shelf petroleum system of the Columbus basin, offshore Trinidad, West Indies, I. Source rock, thermal history, and controls on product distribution, *Marine and Petroleum Geology*, v. 21, p. 97-108.

James, K.H., 2000, The Venezuelan Hydrocarbon Habitat, Part 2: Hydrocarbon Occurrences and Generated-Accumulated Volumes, *Journal of Petroleum Geology*. v. 23, no. 2, p. 133-164.

Pindell, James, and Lorcan Kennan, 2007, Cenozoic Kinematics and Dynamics of Oblique Collision between two Convergent Plate Margins: the Caribbean-South America Collision in Eastern Venezuela, Trinidad and Barbados, *in* The Paleogene of the Gulf of Mexico and Caribbean Basins: Processes, Events, and Petroleum Systems, L. Kennan, J. Pindell, and N.C. Rosen (eds.), 27th Annual Conference Gulf Coast Section SEPM, p. 23-99, Web accessed December 29, 2010, [http://www.tectonicanalysis.com/site/download/abstract\\_caribbean07.htm](http://www.tectonicanalysis.com/site/download/abstract_caribbean07.htm)

Pindell, James, Lorcan Kennan, Walter Maresch, Klaus Stanek, Grenville Draper, and Roger Higgs, 2005, Plate-kinematics and crustal dynamics of circum-Caribbean arc-continent interactions: Tectonic controls on basin development in Proto-Caribbean margins, *in* Caribbean-South American plate interactions, Venezuela, H.G. Ave Lallemant and V.B. Sisson (eds.), Geological Soc. America, Special Paper 394, p. 7-52.

Shi, Xiaobin, Hehua Xu, Xuelin Qiu, Kanyuan Xia, Xiaoqiu Yang, and Yamin Li, 2008, Numerical modeling on the relationship between thermal uplift and subsequent rapid subsidence: Discussions on the evolution of the Tainan Basin, *Tectonics*, v. 27, TC6003.

Sibuet, Jean-Claude, Shu-Kun Hsu, and Eric Debayle, 2004, Geodynamic Context of the Taiwan Orogen, Continent-Ocean Interactions within East Asian Marginal Seas, American Geophysical Union, Geophysical Monograph Series 149, p. 127-158.

Suppe, John, 1984, Kinematics of Arc-Continent Collision, Flipping of Subduction, and Back-Arc Spreading near Taiwan, *Memoir of the Geological Society of China*, no. 6, p. 21-33.

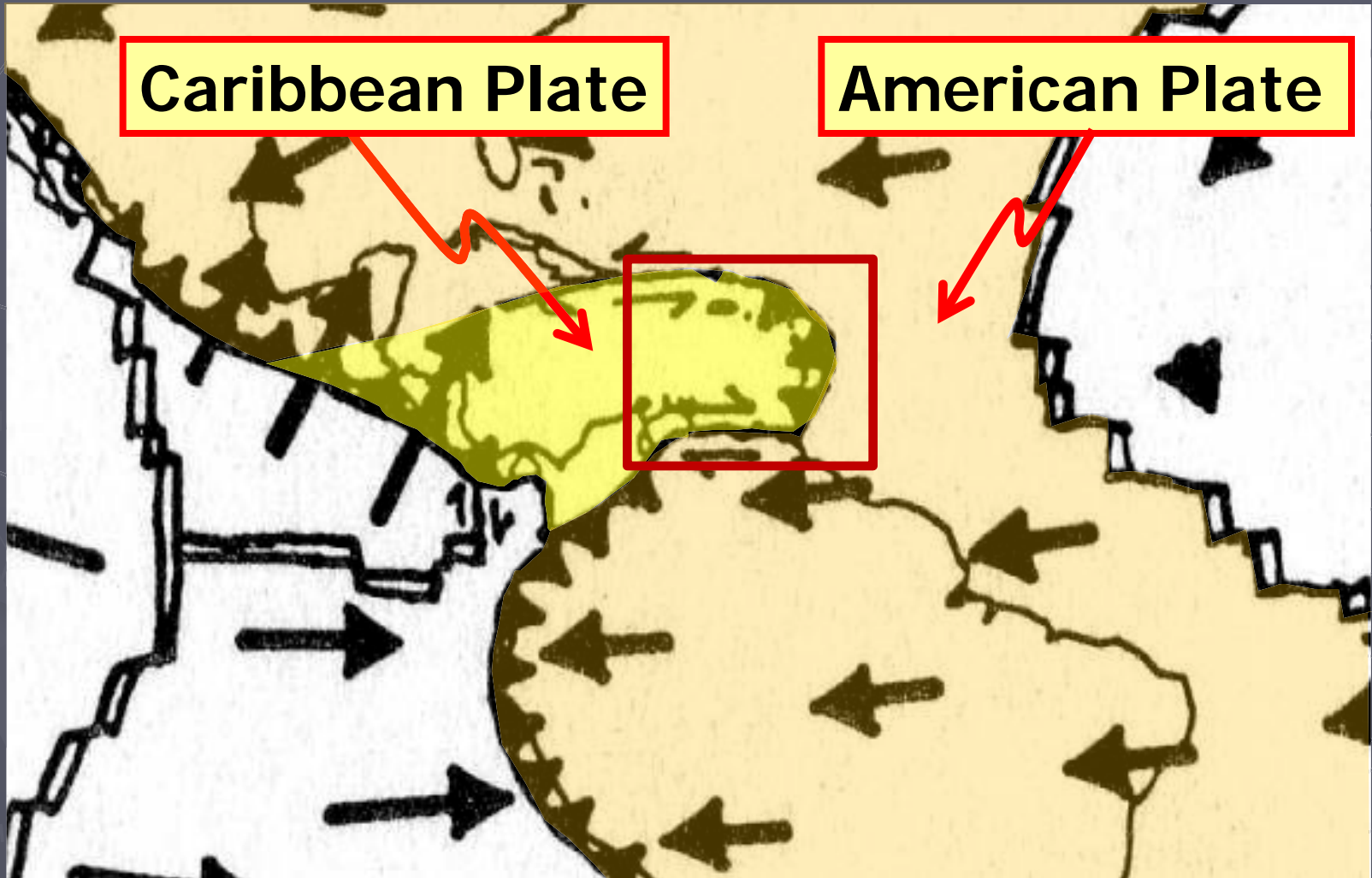
# Arc–Continent Collision: a comparison of the SE Caribbean and Taiwan-Ryukyu margins

J.P. (Paddy) Chesterman

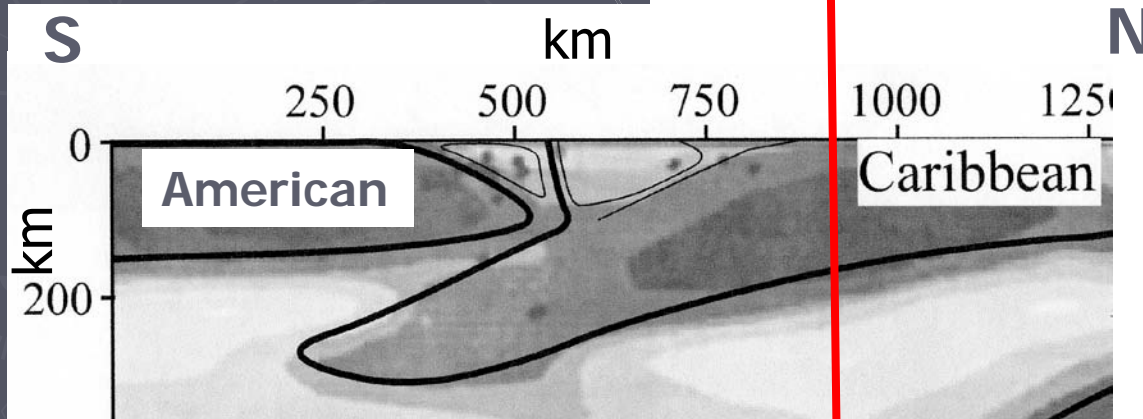
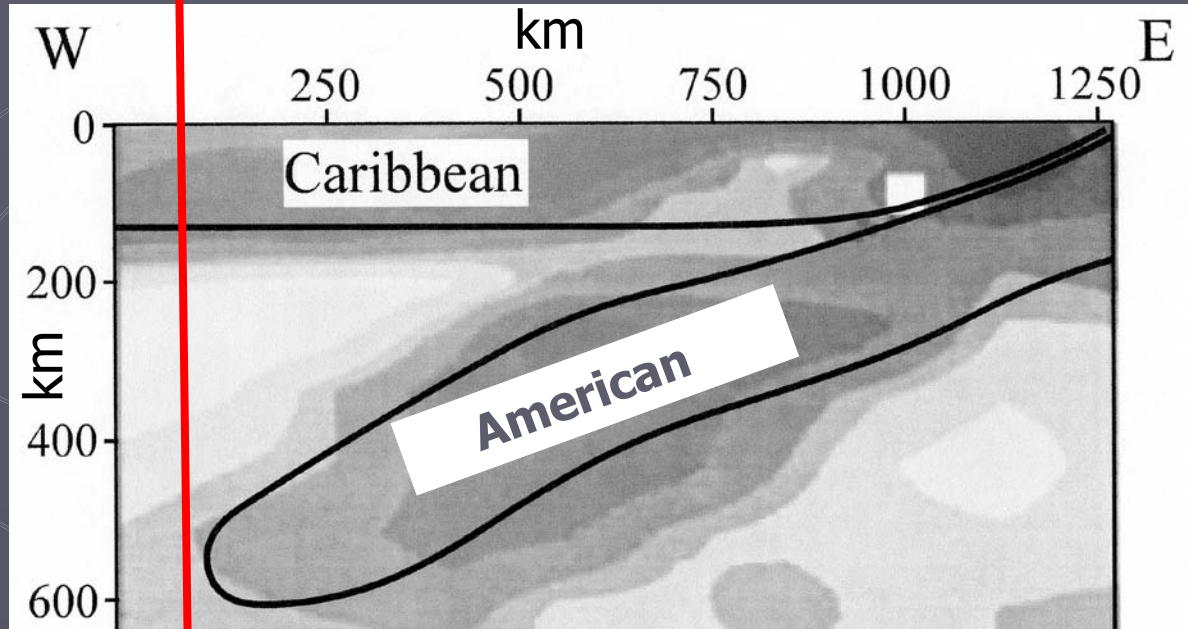
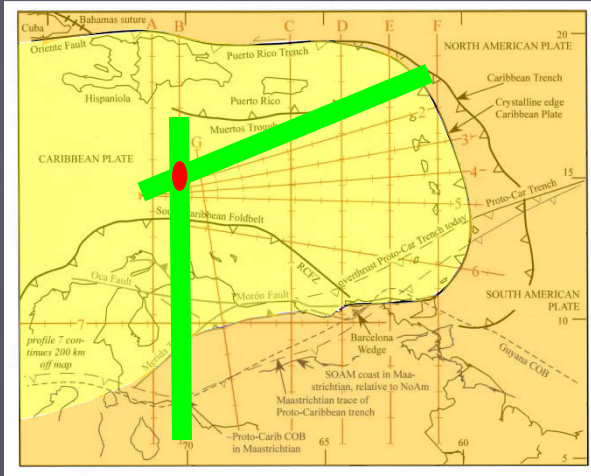
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# Americas – Plate Motion

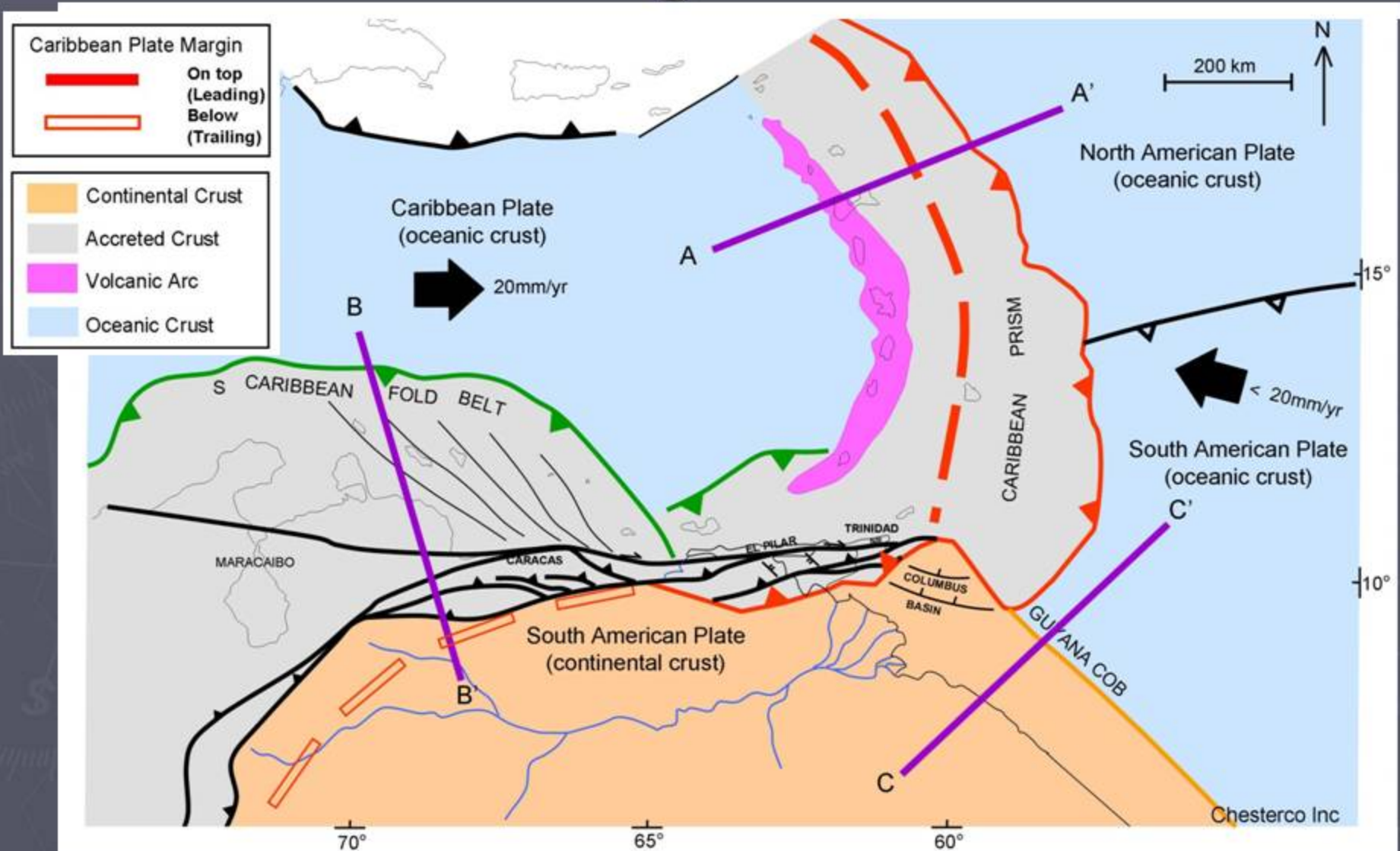


# SE Caribbean – Seismic tomography



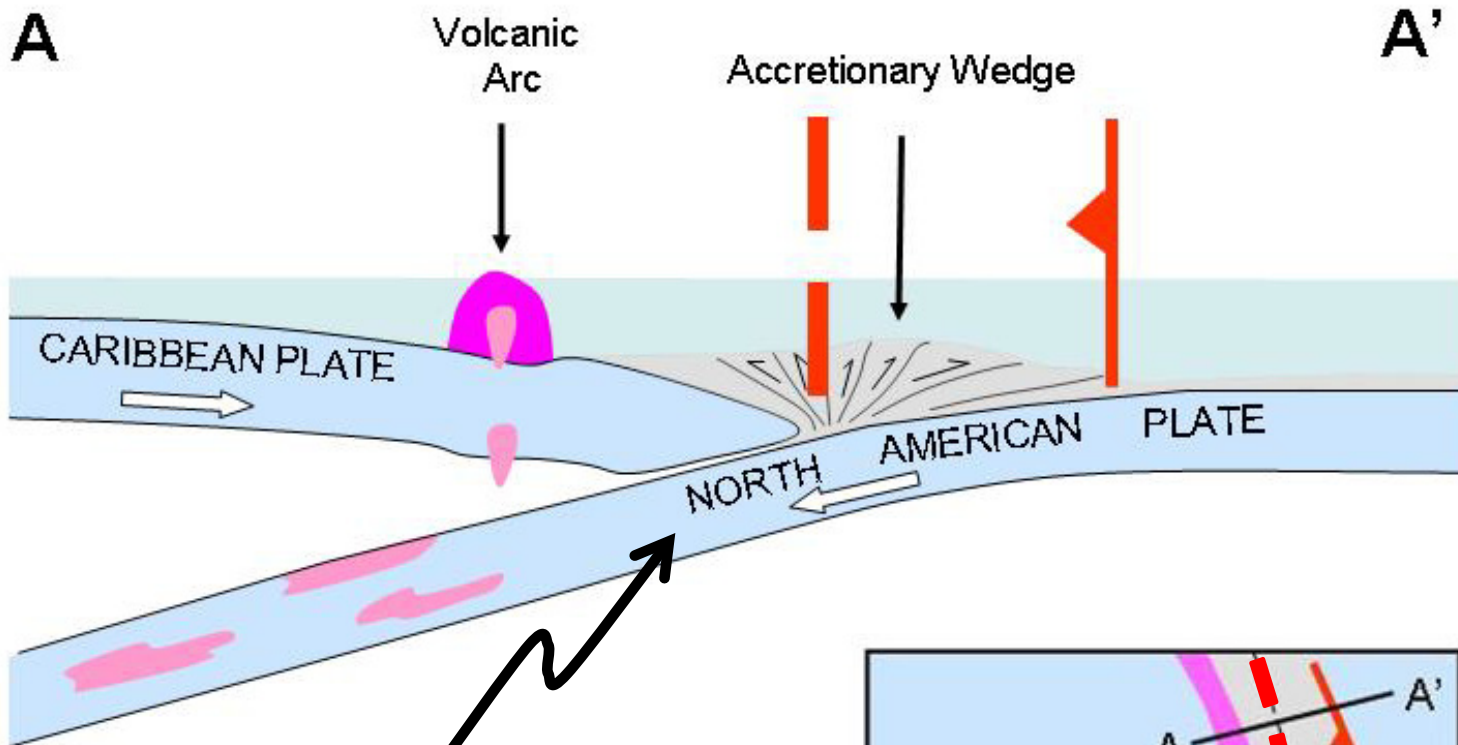
After Pindell & Kennan (2007)

# SE Caribbean – Present day plate configuration

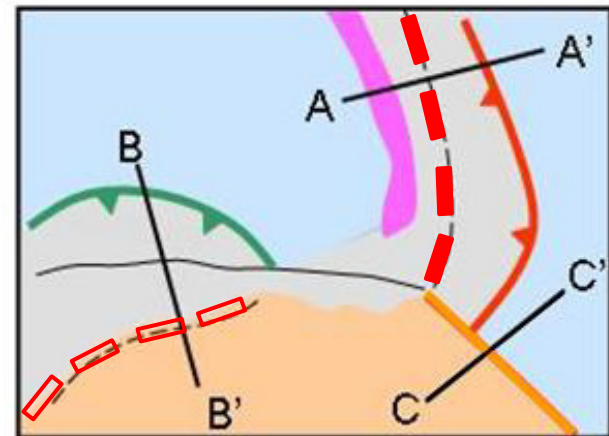




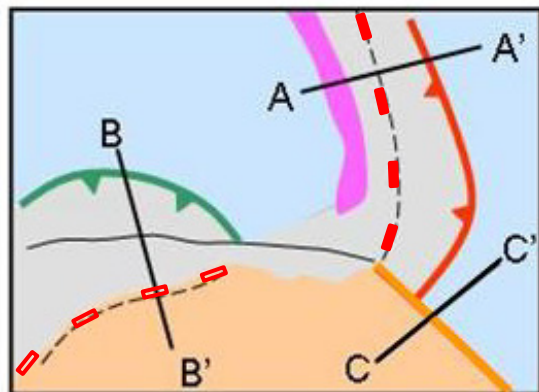
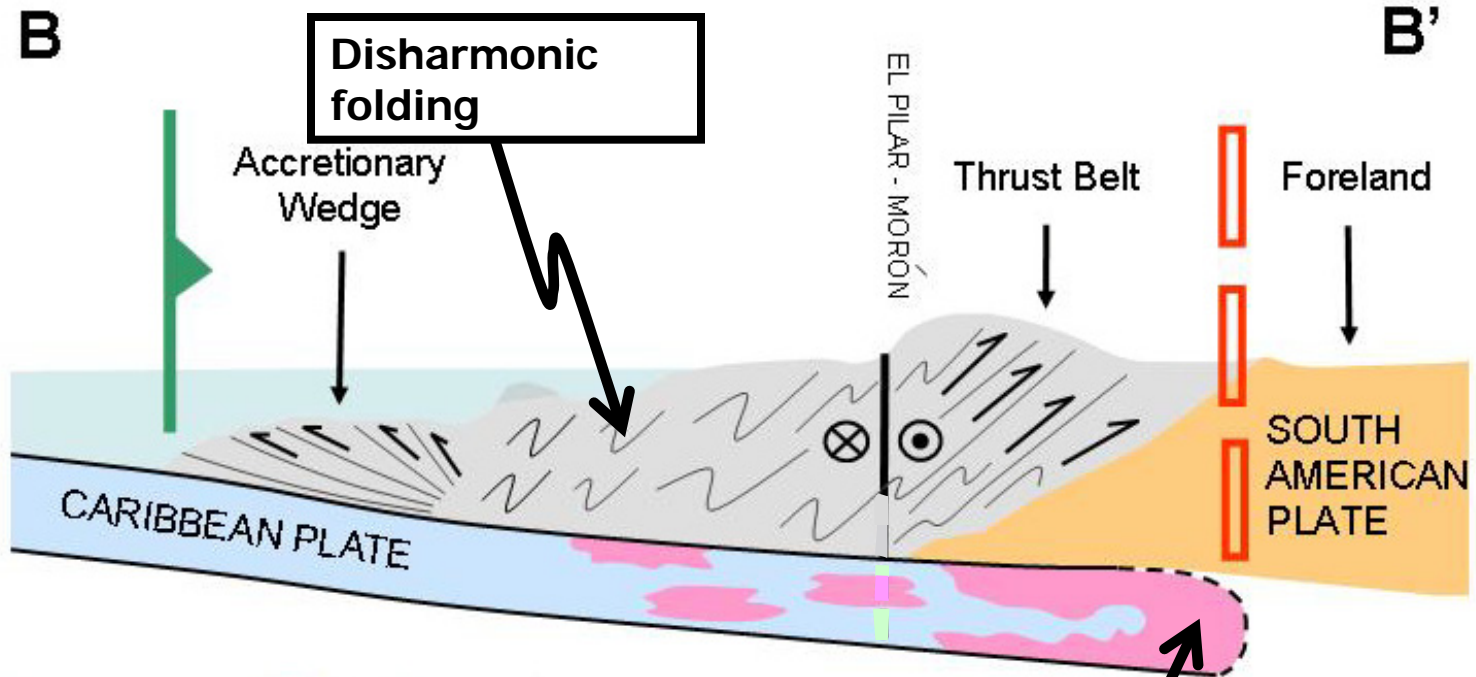
# Lesser Antilles Arc – Leading margin of Caribbean Plate



Caribbean plate advance driven by descending North American plate

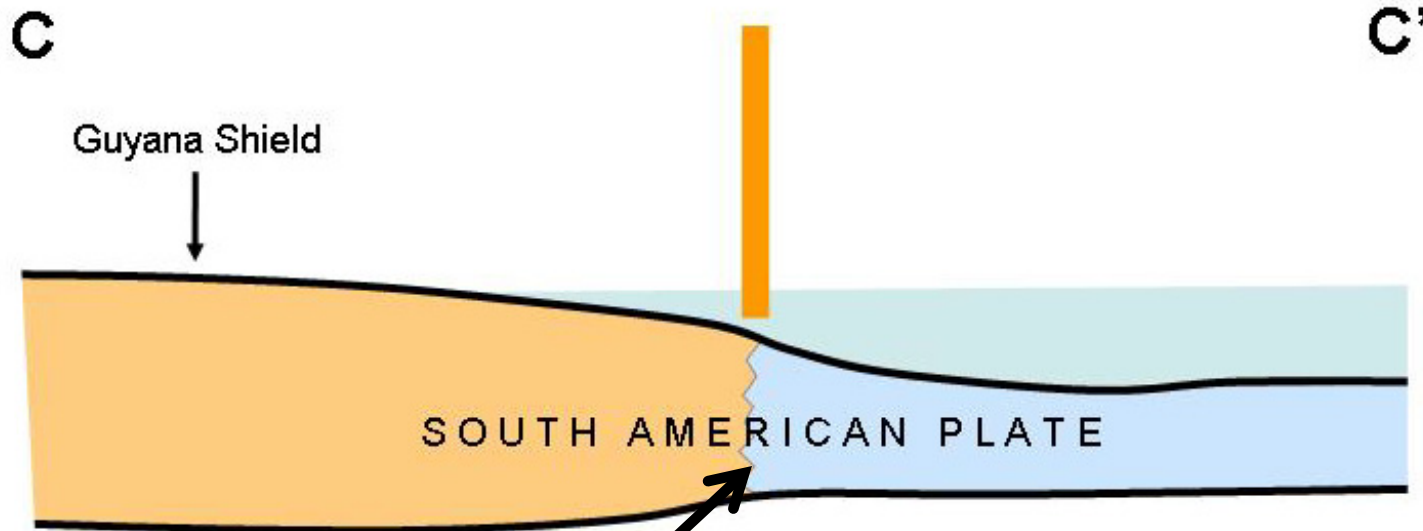


# Orchila Arc – Trailing margin of Caribbean Plate

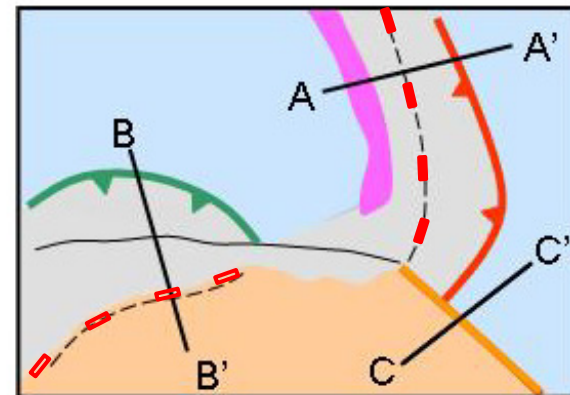


Caribbean plate melting beneath S American plate

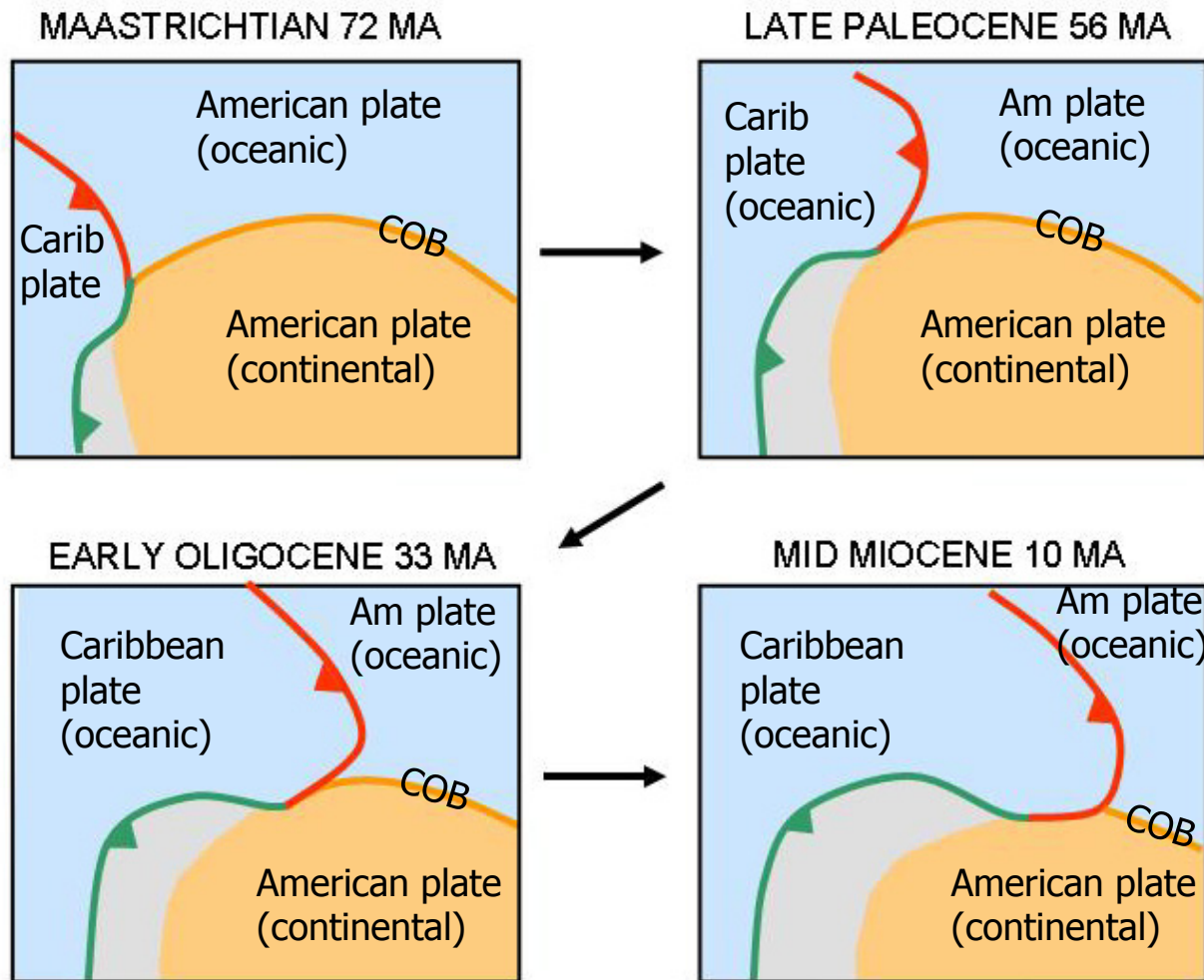
# Guyana continent-ocean boundary (COB)



## Inactive former transform margin remains zone of weakness

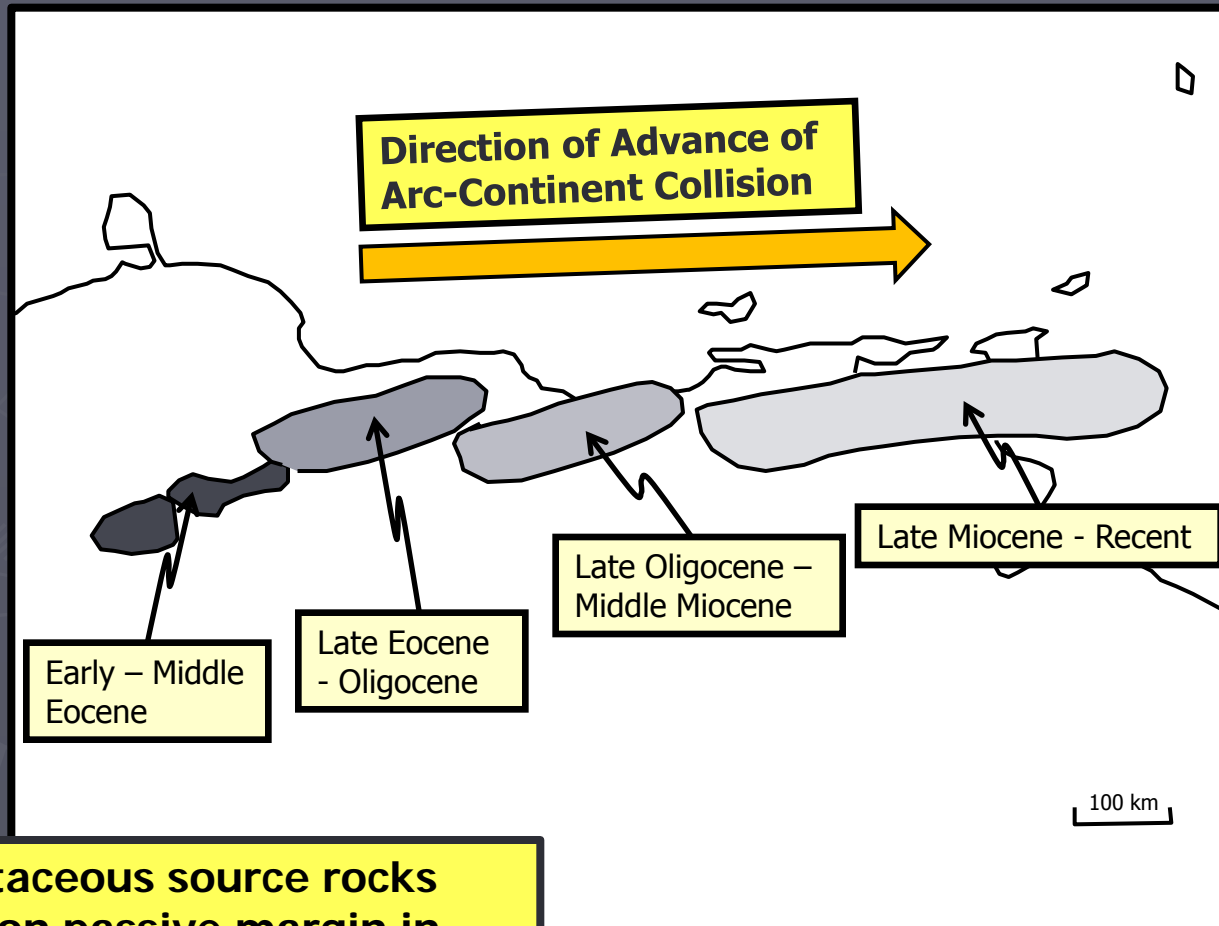


# Advance of SE Caribbean collision along Continent–Ocean Boundary



After Pindell et al (2005)

# Compilation of remnant kitchen areas for U Cretaceous passive margin source rocks



**Upper Cretaceous source rocks deposited on passive margin in advance of arc-continent collision**

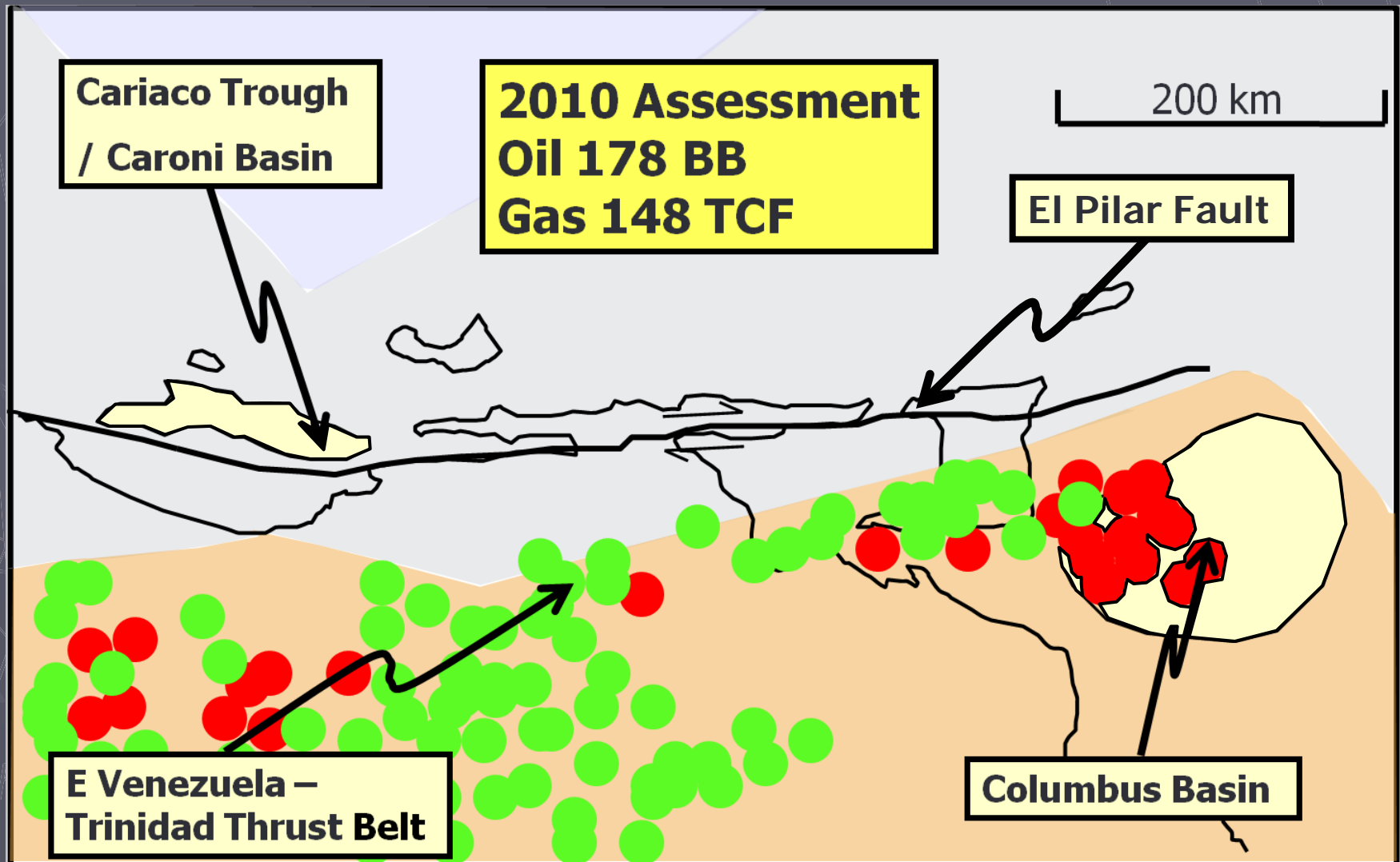


# Significance of arc-continent collision

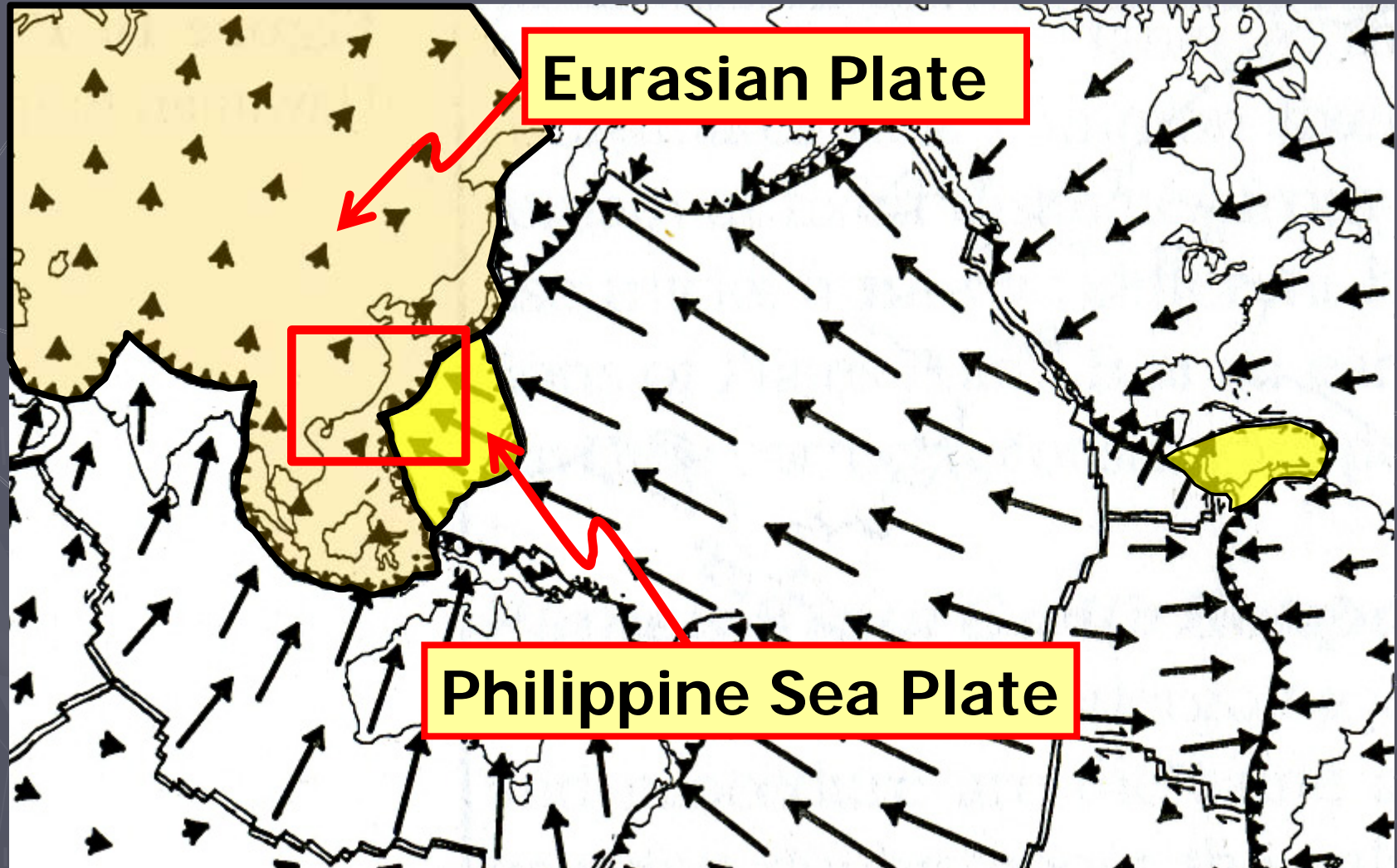
## – Hydrocarbon machine

- ▶ Crustal loading in advance of collision
- ▶ Creates major accommodation space for sedimentation (reservoir development)
- ▶ Pushes former passive margin source rocks down into generating window (source maturation below reservoir)
- ▶ Allows space for subsequent tectonic stacking of recently deposited sediments (trap development)

# East Venezuela Basin – Ultimate Recoverable Reserves (IHS)

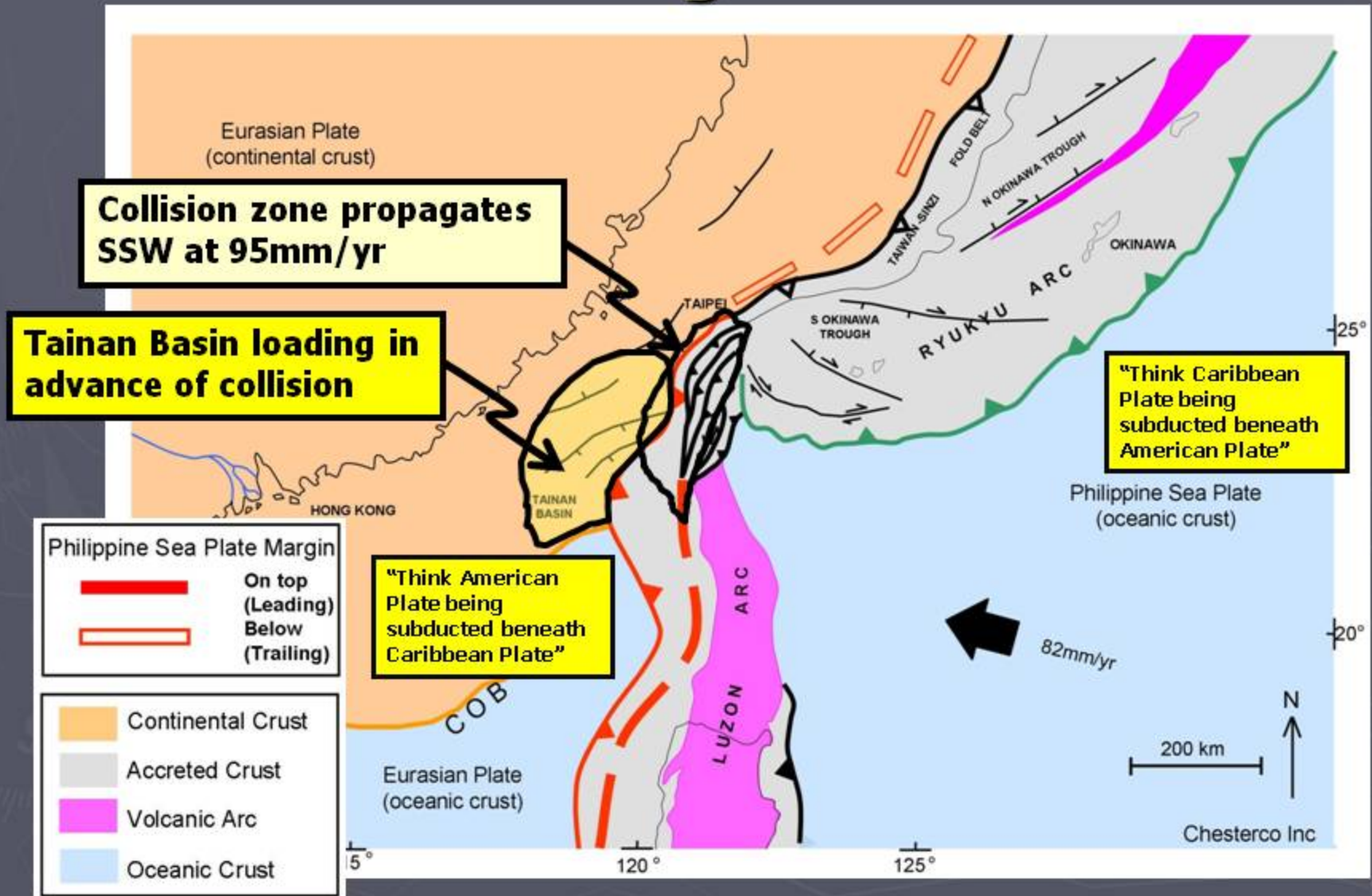


# Asia-Pacific – Plate Motion

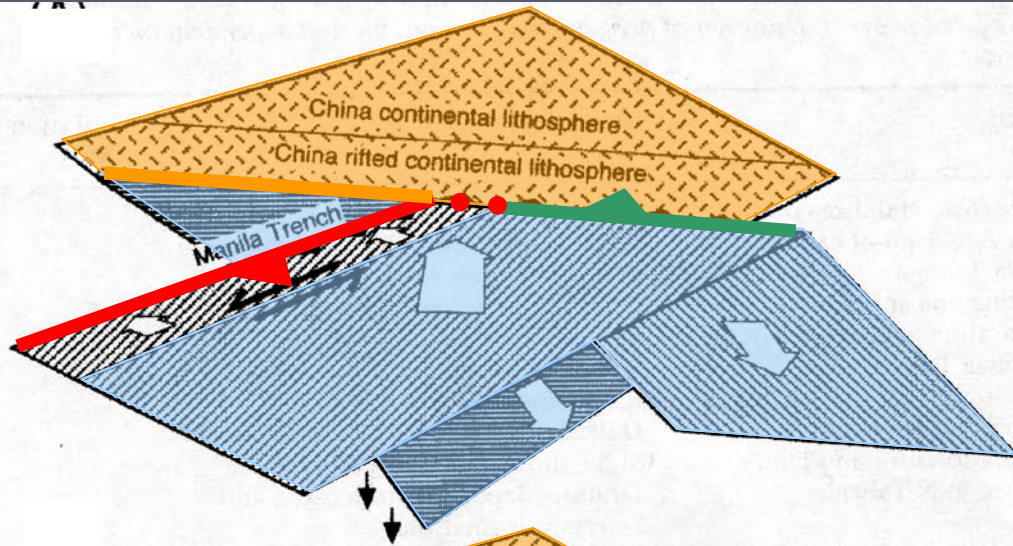




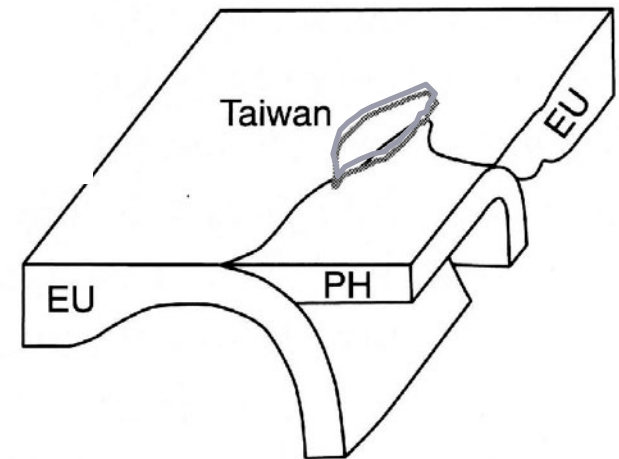
# Taiwan-Ryukyu – Present day plate configuration



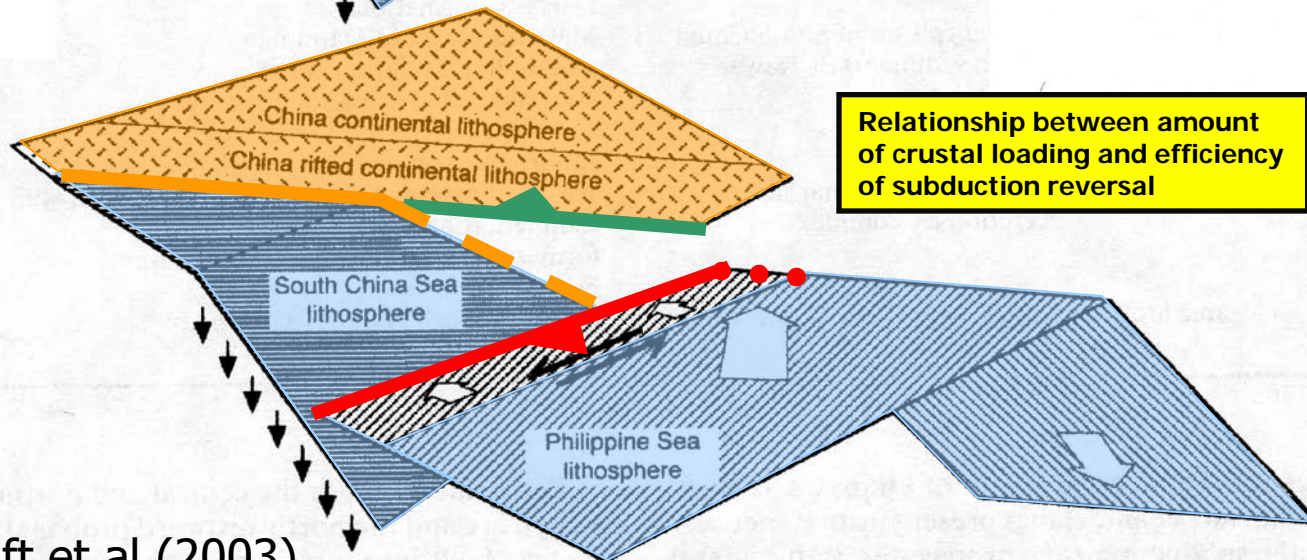
# Taiwan-Ryukyu - Models of continuous arc accretion



Sibuet et al (2004)



Relationship between amount of crustal loading and efficiency of subduction reversal

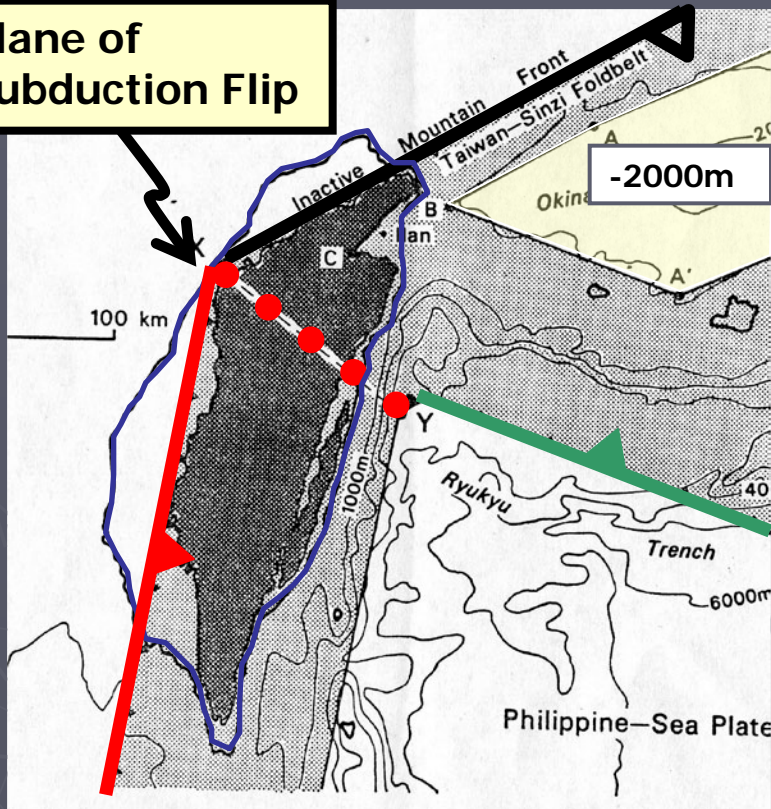


Clift et al (2003)



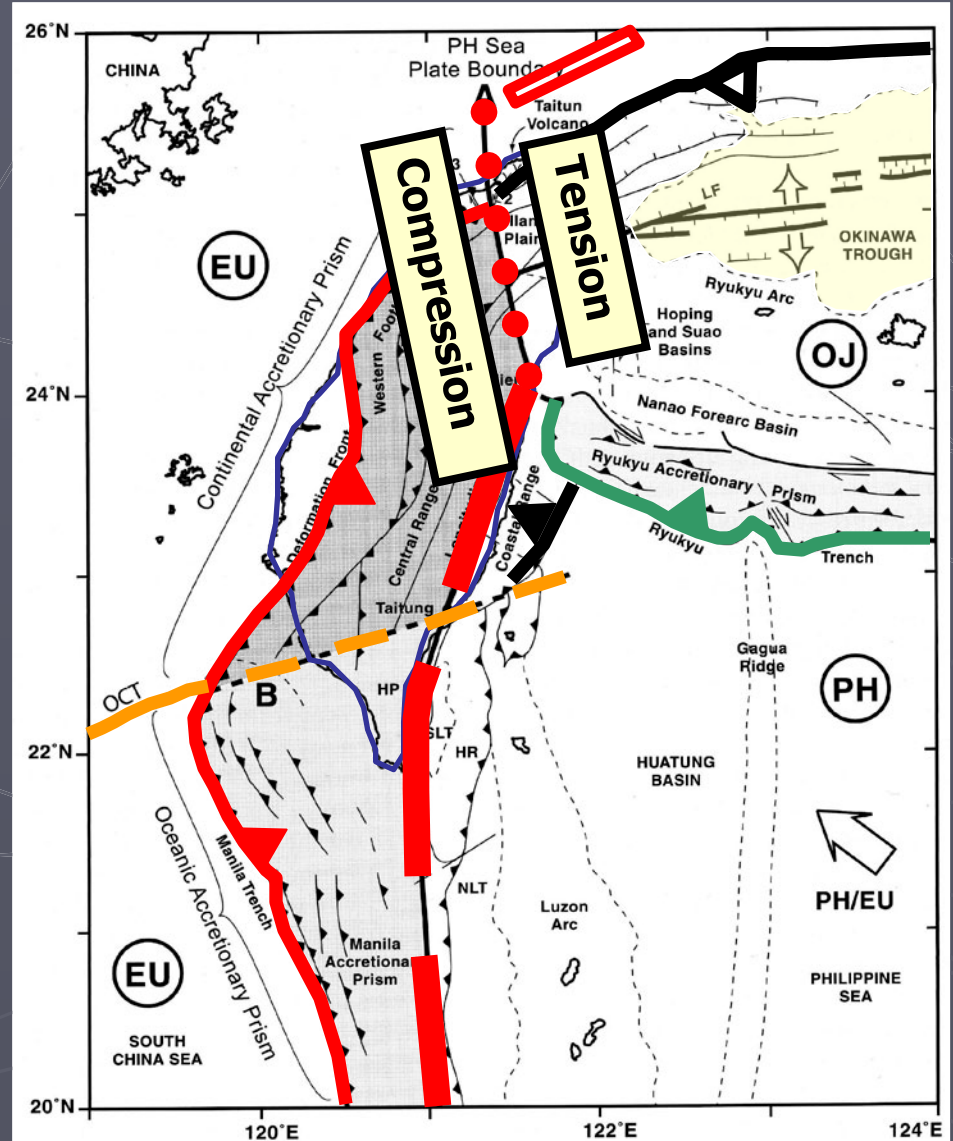
# Subduction Flip or Orogenic Collapse

Plane of Subduction Flip

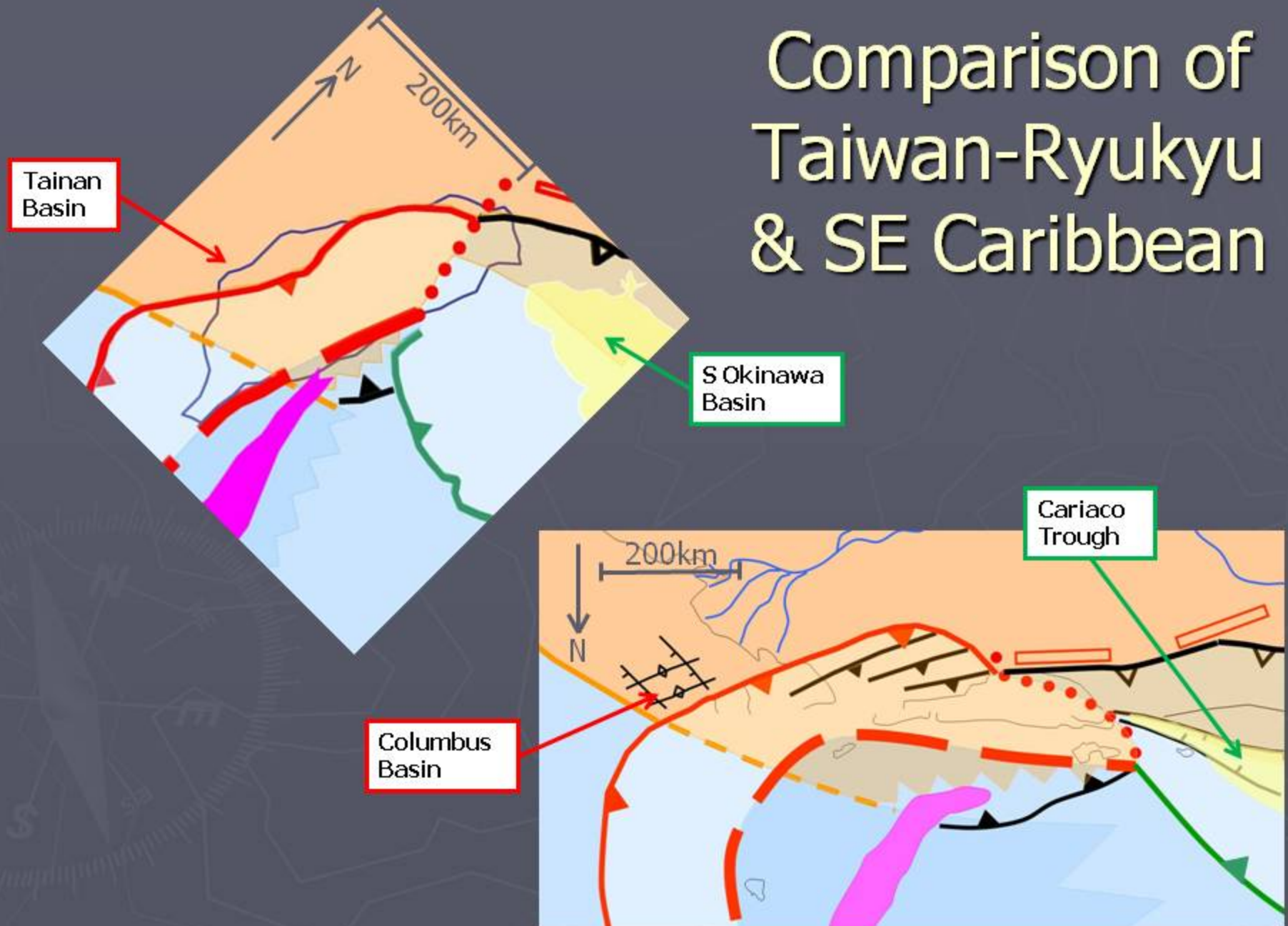


Suppe (1984)

Sibuet et al (2004)



# Comparison of Taiwan-Ryukyu & SE Caribbean

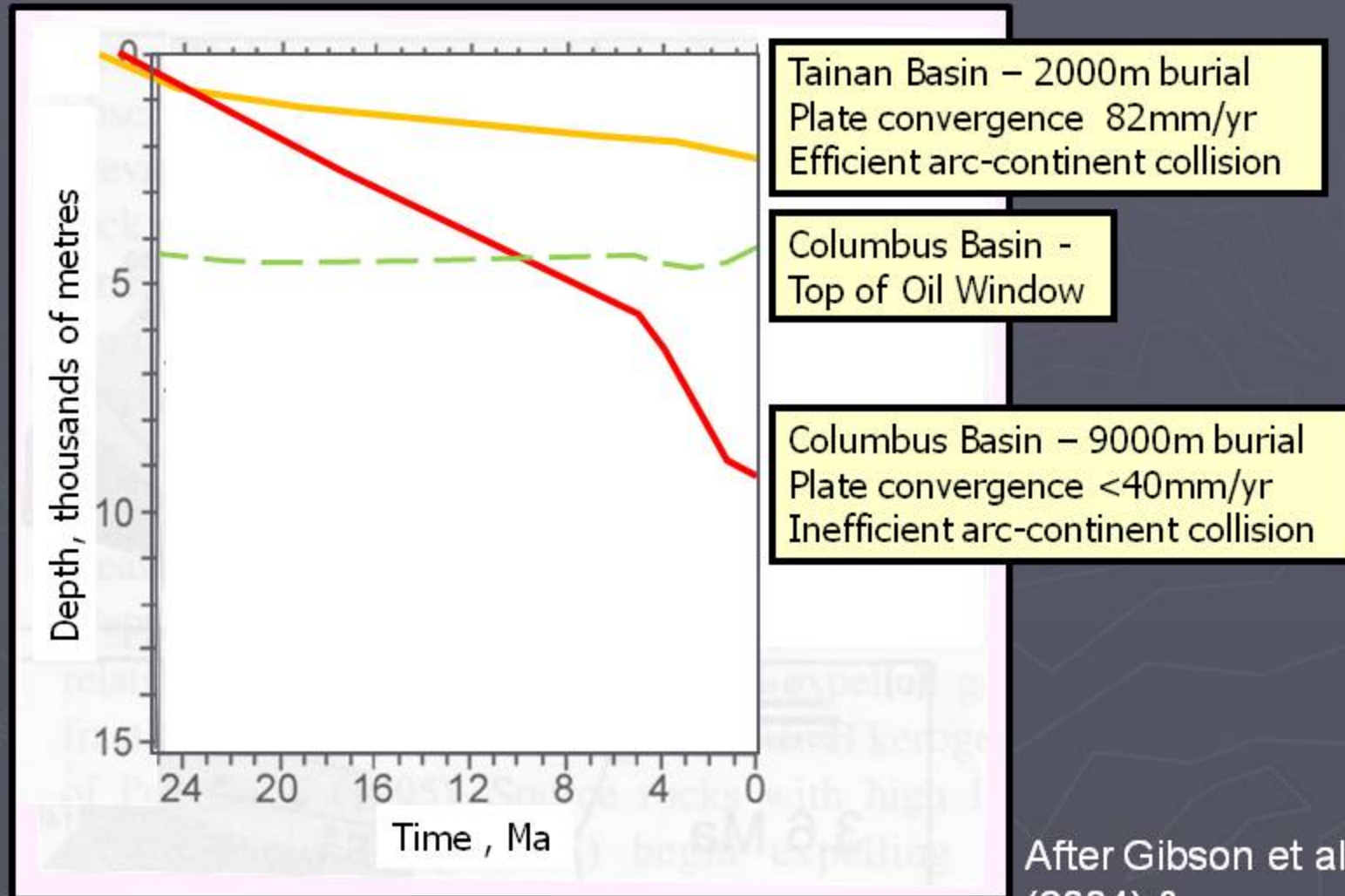


# Initial Conclusions

- ▶ Taiwan-Ryukyu model does apply to SE Caribbean margin
- ▶ By analogy with the East Venezuela Basin, the Tainan Basin seems worthy of exploration interest but has yet to realise major potential



# Columbus and Tainan Basins – Comparison of Burial History Curves



After Gibson et al  
(2004) &  
Shi et al (2008)

# Final Conclusion

- ▶ Possible inverse relationship between plate convergence efficiency and crustal loading in advance of collision
- ▶ Hence similar inverse relationship between plate convergence efficiency and source maturation
- ▶ We should therefore expect greater potential from petroleum systems developed in advance of inefficient arc-continent collisions

# References 1

- ▶ Clift, Peter D.; Schouten, Hans; and Draut, Amy E. (2003) A general model of arc-continent collision and subduction polarity reversal from Taiwan and the Irish Caledonides; from Larter, R.D. & Leat P.T. *Intra-Oceanic Subduction Systems: Tectonic and Magmatic Processes. Geological Society, London, Special Publications, 219, 81-98.*
- ▶ Cox, Allan; and Hart, R. Brian (1986) Plate Tectonics: how it works. Blackwell 392pp
- ▶ Gibson, Richard G. et al (2004) Shelf petroleum system of the Columbus basin, offshore Trinidad, West Indies. I. Source rock, thermal history, and controls on product distribution; Marine and Petroleum Geology 21 97-108
- ▶ James K.H. (2000) The Venezuelan Hydrocarbon Habitat, Part 2: Hydrocarbon Occurrences and Generated-Accumulated Volumes; Journal of Petroleum Geology Volume 23(2) 133-164
- ▶ Pindell, James et al (2005) Plate-kinematics and crustal dynamics of circum-Caribbean arc-continent interactions: Tectonic controls on basin development in Proto-Caribbean margins; from Ave Lallemant H.G. & Sisson V.B. *Caribbean – South American plate interactions, Venezuela Geol. Soc. Am. Spec. Paper 394, 7-52.*



# References 2

- ▶ Pindell, James and Kennan, Lorcan (2007) Cenozoic Kinematics and Dynamics of Oblique Collision between two Convergent Plate Margins: the Caribbean – South America Collision in Eastern Venezuela, Trinidad and Barbados; from Kennan L., Pindell J. & Rosen N. C. *The Paleogene of the Gulf of Mexico and Caribbean Basins: Processes, Events, and Petroleum Systems 27th Annual Conference Gulf Coast Section SEPM* 23-99
- ▶ Shi, Xiaobin et al (2008) Numerical modeling on the relationship between thermal uplift and subsequent rapid subsidence: Discussions on the evolution of the Tainan Basin; *Tectonics* Volume 27 TC6003
- ▶ Sibuet, Jean-Claude; Hsu, Shu-Kun: and Debayle, Eric (2004) Geodynamic Context of the Taiwan Orogen; from *Continent-Ocean Interactions within East Asian Marginal Seas. American Geophysical Union, Geophysical Monograph Series 149, 127-158*
- ▶ Suppe, John (1984) Kinematics of Arc-Continent Collision, Flipping of Subduction, and Back-Arc Spreading near Taiwan; *Memoir of the Geological Society of China* No. 6 21-33