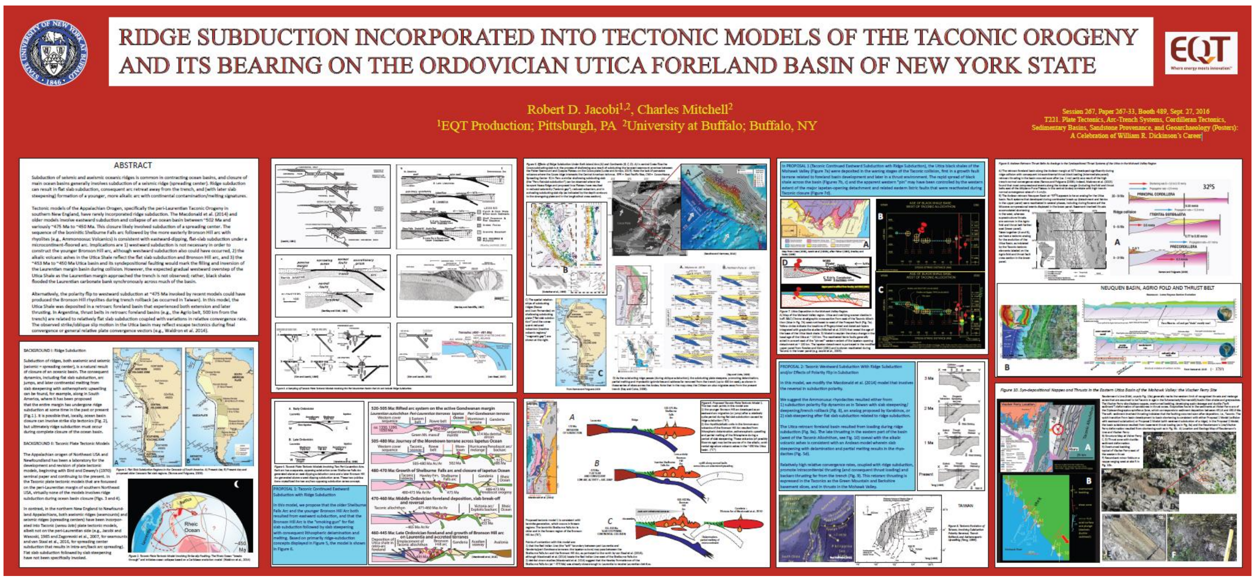
RIDGE SUBDUCTION INCORPORATED INTO TECTONIC MODELS OF THE TACONIC OROGENY AND ITS BEARING ON THE ORDOVICIAN UTICA FORELAND BASIN OF NEW YORK STATE

Robert D. Jacobi[1,2], Charles Mitchell[2]

[1]EQT Production; Pittsburgh, PA [2]University at Buffalo; Buffalo, NY

Session 267, Paper 267-33, Booth 489, Sept. 27, 2016
T221. Plate Tectonics, Arc-Trench Systems, Cordilleran Tectonics,
Sedimentary Basins, Sandstone Provenance, and Geoarchaeology (Posters):
A Celebration of William R. Dickinson's Career



ABSTRACT

Subduction of seismic and aseismic oceanic ridges is common in contracting ocean basins, and closure of main ocean basins generally involve subduction of a seismic ridge (spreading center). Ridge subduction can result in flat slab subduction, consequent arc retreats away from the trench, and (with later slab steepening) formation of a younger, more alkalic arc with continental contamination/melting signatures. Tectonic models of the Appalachian Orogen, specifically the peri-Laurentian Taconic Orogeny in southern New England, have rarely incorporated ridge subduction. The Macdonald et al. (2014) and older models involve eastward subduction and collapse of an ocean basin between ~502 Ma and variously ~475 Ma to ~450 Ma. This closure likely involved subduction of a spreading center. The sequence of the boninitic Shelburne Falls arc followed by the more easterly Bronson Hill arc with rhyolites (e.g., Ammonoosuc Volcanics) is consistent with eastward-dipping, flat-slab subduction under a microcontinent-floored arc. Implications are 1) westward subduction is not necessary in order to construct the younger Bronson Hill arc, although westward subduction also could have occurred, 2) the alkalic volcanic ashes in the Utica Shale reflect the flat slab subduction and Bronson Hill arc, and 3) the ~453 Ma to ~450 Ma Utica basin and its syndepositional faulting would mark the filling and inversion of the Laurentian margin basin during collision. However, the expected gradual westward overstep of the Utica Shale as the Laurentian margin approached the trench is not observed; rather, black shales flooded the Laurentian carbonate bank synchronously across much of the basin.

Alternatively, the polarity flip to westward subduction at ~475 Ma invoked by recent models could have produced the Bronson Hill rhyolites during trench rollback (as occurred in Taiwan). In this model, the Utica Shale was deposited in a retroarc foreland basin that experienced both extension and later thrusting. In Argentina, thrust belts in retroarc foreland basins (e.g., the Agrio belt, 500 km from the trench) are related to relatively flat slab subduction coupled with variations in relative convergence rate. The observed strike/oblique slip motion in the Utica basin may reflect escape tectonics during final convergence or general relative plate convergence vectors (e.g., Waldron et al. 2014).

BACKGROUND I: *Ridge Subduction*

Subduction of ridges, both aseismic and seismic (seismic = spreading center), is a natural result of closure of an oceanic basin. The consequent dynamics, including flat slab subduction, arc jumps, and later continental melting from slab steepening with asthenospheric upwelling can be found, for example, along in South America, where it has been proposed that the entire margin has undergone ridge subduction at some time in the past or present (Fig. 1). It is possible that, locally, ocean basin closure can involve strike slip tectonics (Fig. 2), but ultimately ridge subduction must occur during complete closure of the ocean basin.

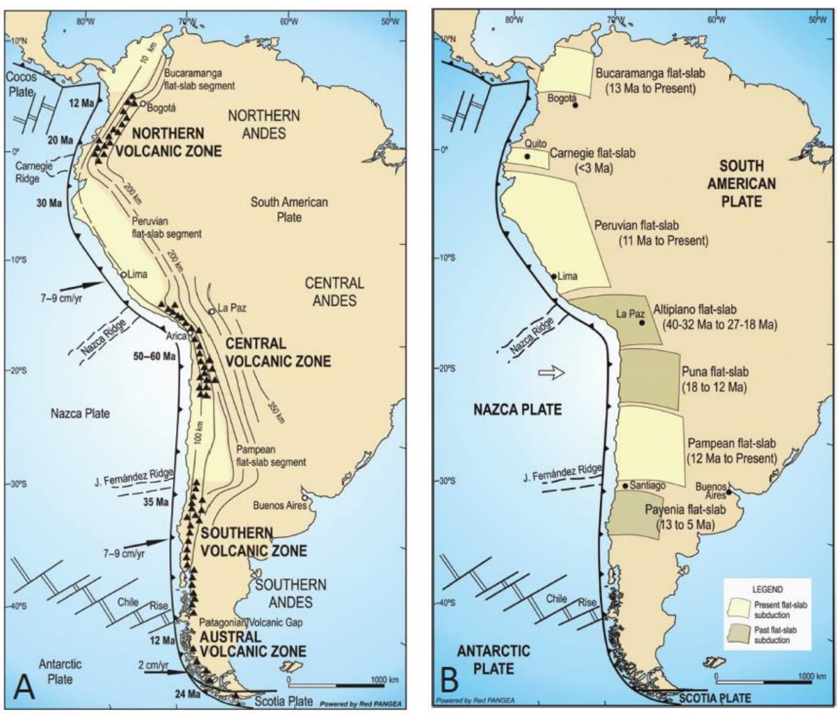


Figure 1. Flat Slab Subduction Regions in the Cenozoic of South America. A) Present day. B) Present day and proposed older Cenozoic flat slab regions. (Romos and Folguera, 2009).

BACKGROUND II: *Taconic Plate Tectonic Models*

The Appalachian orogen of Northeast USA and Newfoundland has been a laboratory for the development and revision of plate tectonic models, beginning with Bird and Dewey's (1970) seminal paper and continuing to the present. In the Taconic plate tectonic models that are focused on the peri-Laurentian margin of southern Northeast USA, virtually none of the models involves ridge subduction during ocean basin closure (Figs. 3 and 4).

In contrast, in the northern New England to Newfoundland Appalachians, both aseismic ridges (seamounts) and seismic ridges (spreading centers) have been incorporated into Taconic (sensu lato) plate tectonic

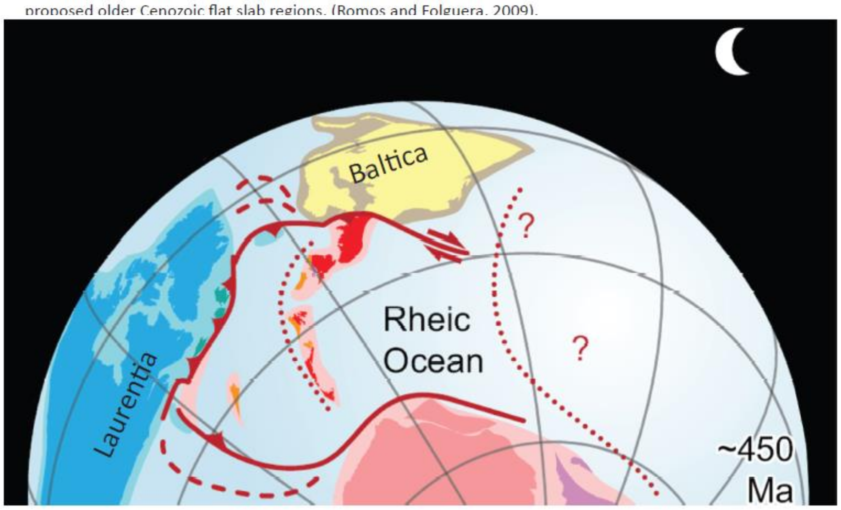


Figure 2. Taconic Plate Tectonic Model Involving Strike-slip Faulting. The Rheic Ocean "breaks through" and initiates ocean collapse based on a Caribbean evolution model (Waldron et al., 2014)

models, albeit not on the peri-Laurentian side (e.g., Jacobi and Wasowski, 1985 and Zagorevski et al., 2007, for seamounts and van Staal et al., 2016, for spreading center subduction that results in intra-arc/back arc spreading). Flat slab subduction followed by slab steepening have not been specifically invoked.

TACONIC PLATE TECTONIC PROPOSAL 1:
Taconic Continued Eastward Subduction with Ridge Subduction

In this model, we propose that the older Shelburne Falls Arc and the younger Bronson Hill Arc both resulted from eastward subduction, and that the Bronson Hill Arc is the “smoking gun” for flat slab subduction followed by slab steepening with consequent lithospheric delamination and melting. Based on primarily ridge-subduction concepts displayed in Figure 5, the model is shown in Figure 6.

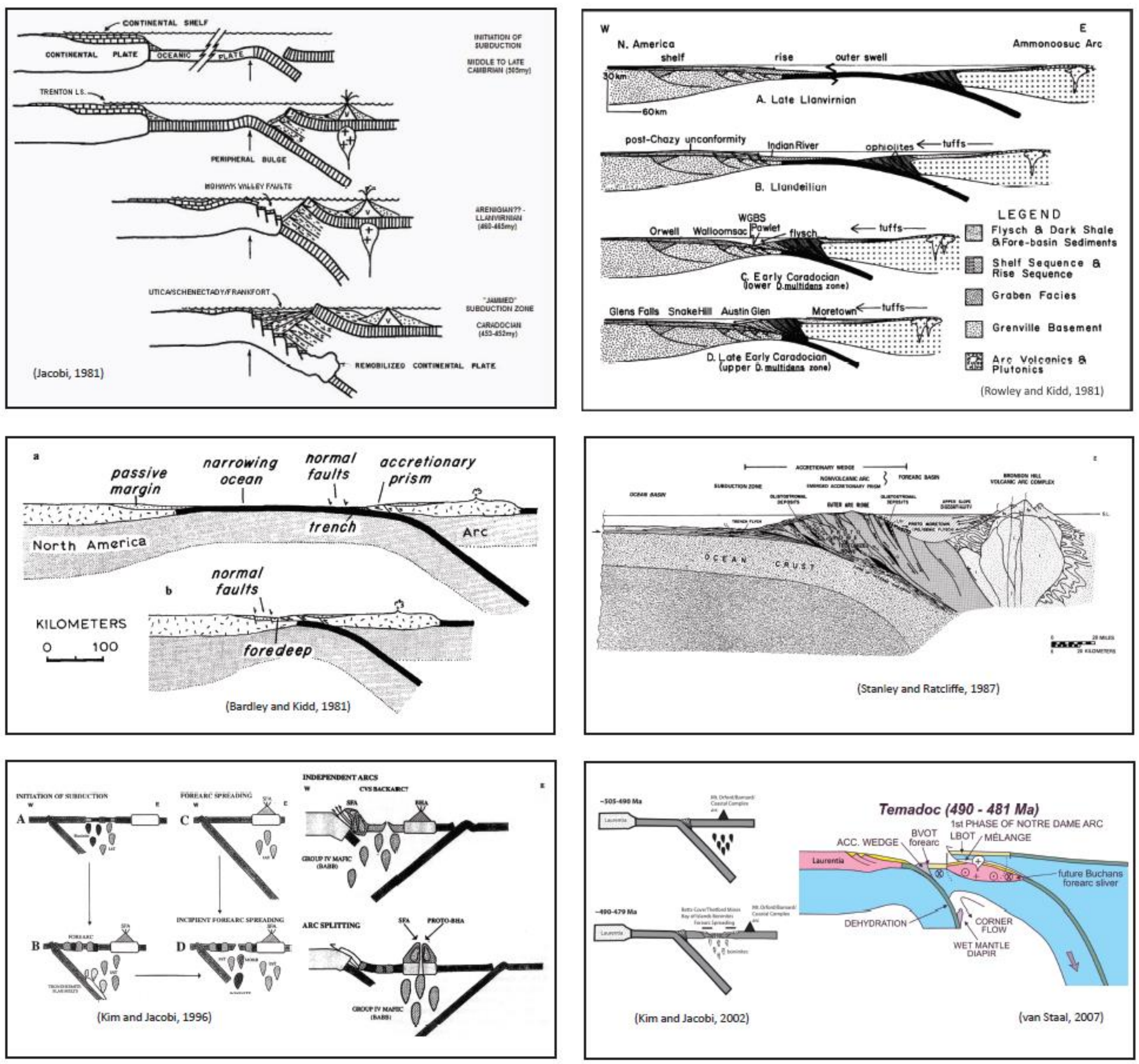


Figure 3. A Sampling of Taconic Plate Tectonic Models Involving the Peri-laurentian Realm that do not Include Ridge Subduction.

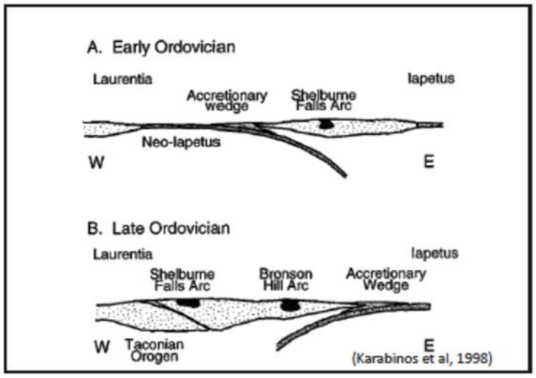


Figure 4. Taconic Plate Tectonic Models Involving Two Peri-Lauentian Arcs. Each arc has a separate, opposing subduction zone: Shelburne Falls Arc generated above an east-dipping subduction zone and a later Bronson Hill Arc generated above a west-dipping subduction zone. These two publications crystallized the two arc/two opposing subduction zones concept.

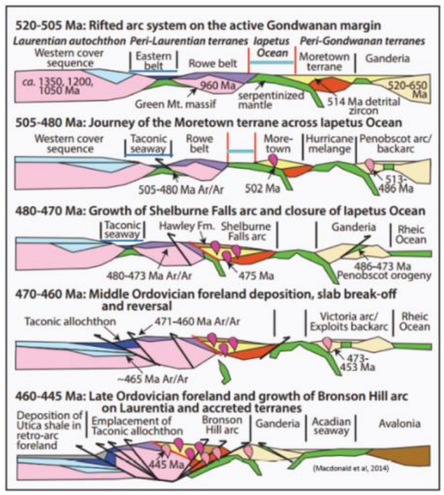
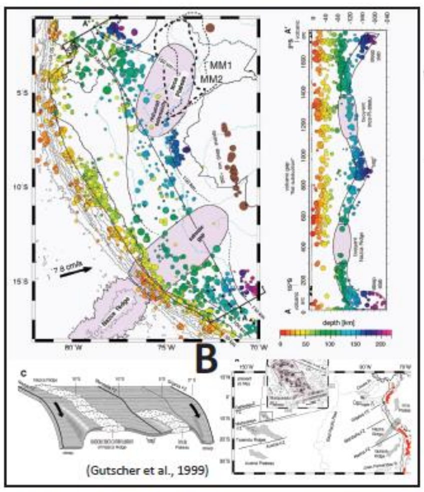
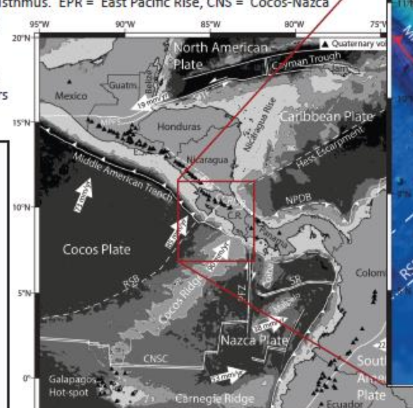
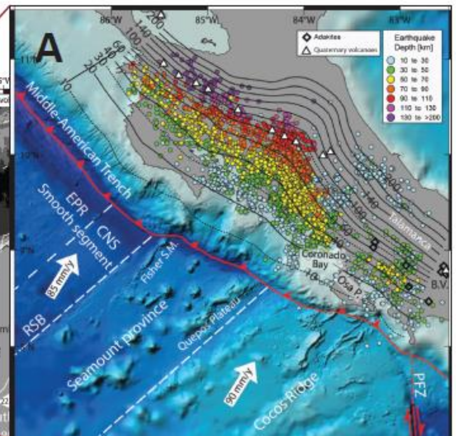


Figure 5. Effects of Ridge Subduction Under Both Island Arcs (A) and Continents (B, C, D). A) In central Costa Rica the Cocos subducting slab is in the process of shallowing as a result of subducting the bouyant seamount province between the Fisher Seamount and Quepos Plateau on the Cocos plate (Lucke and Arroyo, 2015). Note the lack of pervasive volcanos where the Cocos ridge intersects the Central American Isthmus. EPR = East Pacific Rise, CNS = Cocos-Nazca Spreading Center B) In Peru a similar shallowing subducting slab (the "Peru flat-slab subduction") can be observed where the bouyant Nazca Ridge and proposed Inca Plateau have resulted in reduced seismicity ("seismic gap"), reduced volcanism, and in a shoaling subducting slab dip (as indicated by the depth contours to the downgoing plate and in the longitudinal cross-section).

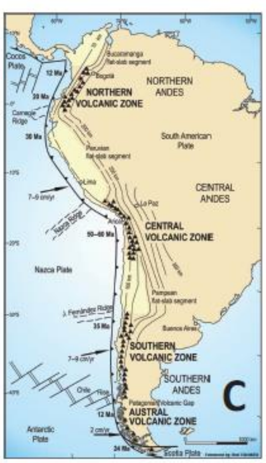




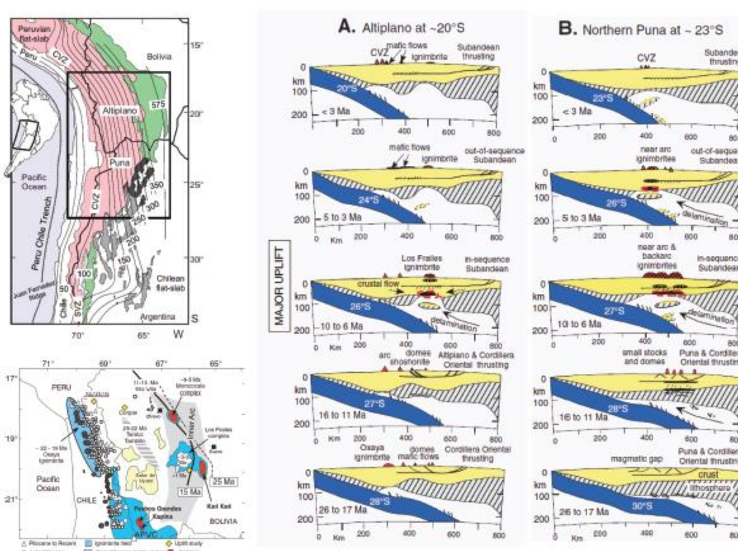


(Baudina and Hermoza, 2014)

C) The spatial relationships of subducting ridges (Nazca and Juan Fernandez) on shallowing subducting plate ("flat slab subduction") and the consequent reduced volcanism (inactive volcanic regions/ "magmatic gap") are shown at the right.



from Ramos and Folguera 2009



(Kay and Coira, 2009)

D) As the subducting ridge passes (during oblique subduction), the subducting plate steepens, promoting delamination, partial melting and rhyodacitic ignimbrites and calderas far removed from the trench (up to 400 km east), as shown in these series of slices across the Andes. Note that in the map view, the Chilean arc also migrates away from the present trench (Kay and Coira, 2009).

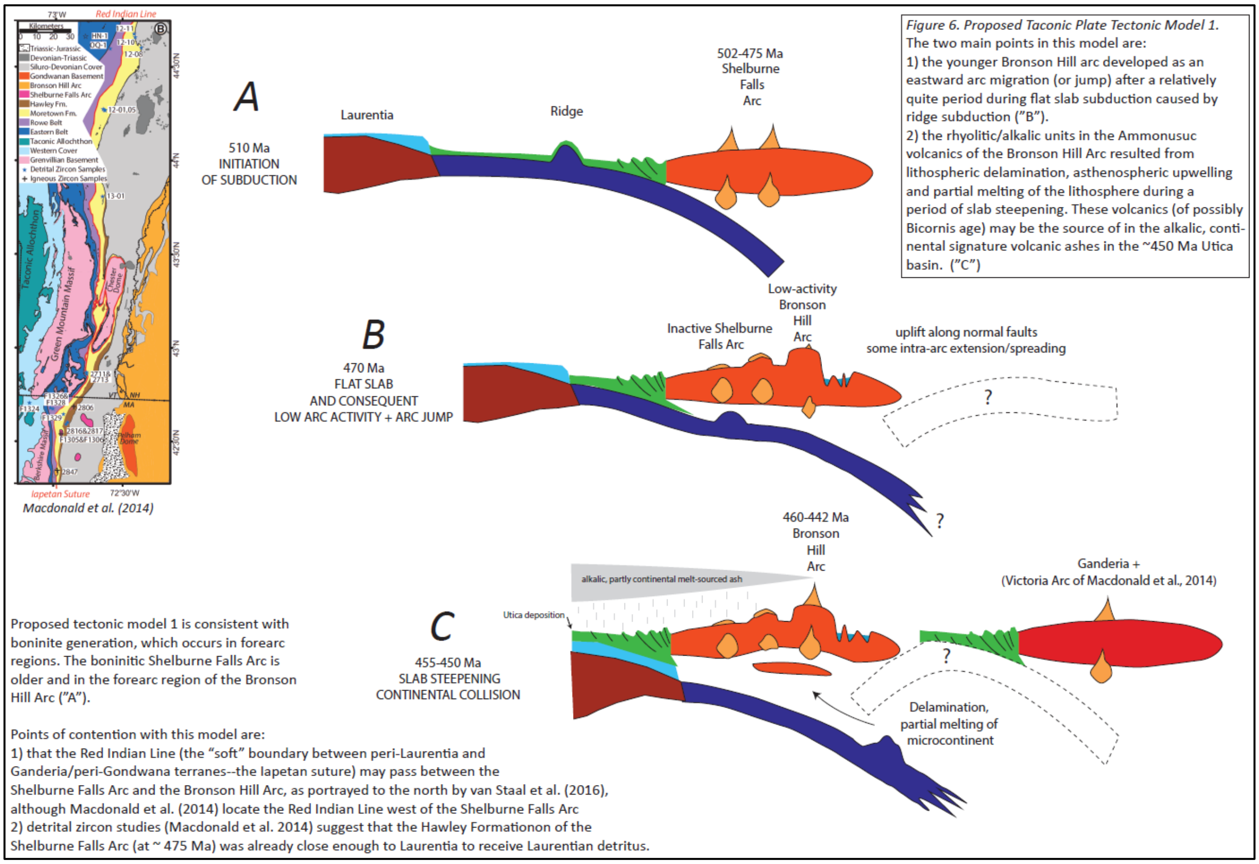


Figure 6. Proposed Taconic Plate Tectonic Model 1.
The two main points in this model are:
1) the younger Bronson Hill arc developed as an eastward arc migration (or jump) after a relatively quite period during flat slab subduction caused by ridge subduction ("B").
2) the rhyolitic/alkalic units in the Ammonusuc volcanics of the Bronson Hill Arc resulted from lithospheric delamination, asthenospheric upwelling and partial melting of the lithosphere during a period of slab steepening. These volcanics (of possibly Bicornis age) may be the source of in the alkalic, continental signature volcanic ashes in the ~450 Ma Utica basin. ("C")

Proposed tectonic model 1 is consistent with boninite generation, which occurs in forearc regions. The boninitic Shelburne Falls Arc is older and in the forearc region of the Bronson Hill Arc ("A").

Points of contention with this model are:
1) that the Red Indian Line (the "soft" boundary between peri-Laurentia and Ganderia/peri-Gondwana terranes--the Iapetan suture) may pass between the Shelburne Falls Arc and the Bronson Hill Arc, as portrayed to the north by van Staal et al. (2016), although Macdonald et al. (2014) locate the Red Indian Line west of the Shelburne Falls Arc
2) detrital zircon studies (Macdonald et al. 2014) suggest that the Hawley Formationon of the Shelburne Falls Arc (at ~ 475 Ma) was already close enough to Laurentia to receive Laurentian detritus.

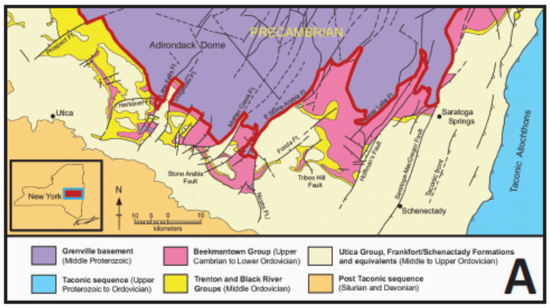
In TACONIC PLATE TECTONIC PROPOSAL 1 (Taconic Continued Eastward Subduction with Ridge Subduction), the Utica black shales of the Mohawk Valley (Figure 7a) were deposited in the waning stages of the Taconic collision, first in a growth fault terrane related to foreland basin development and later in a thrust environment. The rapid spread of black shale across the basin (Figures 7b, c) and the apparent western "pin" may have been controlled by the western extent of the major Iapetan-opening detachment and related eastern listric faults that were reactivated during Taconic closure (Figure 7d).

TACONIC PLATE TECTONIC PROPOSAL 2:
Taconic Westward Subduction with Ridge Subduction and/or Effects of Polarity Flip in Subduction

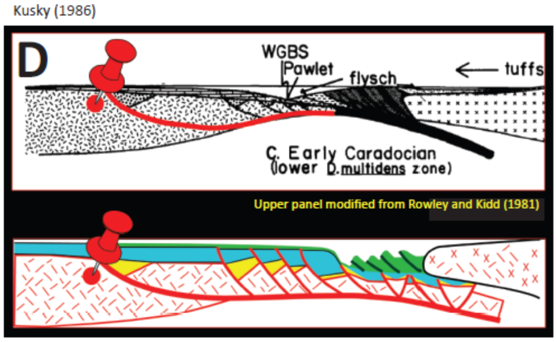
In this model, we modify the Macdonald et al. (2014) model that involves the reversal in subduction polarity. We suggest the Ammonoosuc rhyodacites resulted either from:
1) subduction polarity flip dynamics as in Taiwan with slab steepening/ deepening/trench rollback (Fig. 8), an analog proposed by Karabinos, or
2) slab steepening after flat slab subduction related to ridge subduction.

The Utica retroarc foreland basin resulted from loading during ridge subduction (Fig. 9a). The late thrusting in the eastern part of the basin (west of the Taconic Allochthon, see Fig. 10) coeval with the alkalic volcanic ashes is consistent with an Andean model wherein slab steepening with delamination and partial melting results in the rhyodacites (Fig. 5d).

Relatively high relative convergence rates, coupled with ridge subduction, promote intracontinental thrusting (and consequent thrust loading) and backarc thrusting far from the trench (Fig. 9). This retroarc thrusting is expressed in the Taconics as the Green Mountain and Berkshire basement slices, and in thrusts in the Mohawk Valley (Figs. 9 and 10).



Map from Cross (2008), Jacobi et al (2008b), after Fisher (1980), Bradley and Kusky (1986)



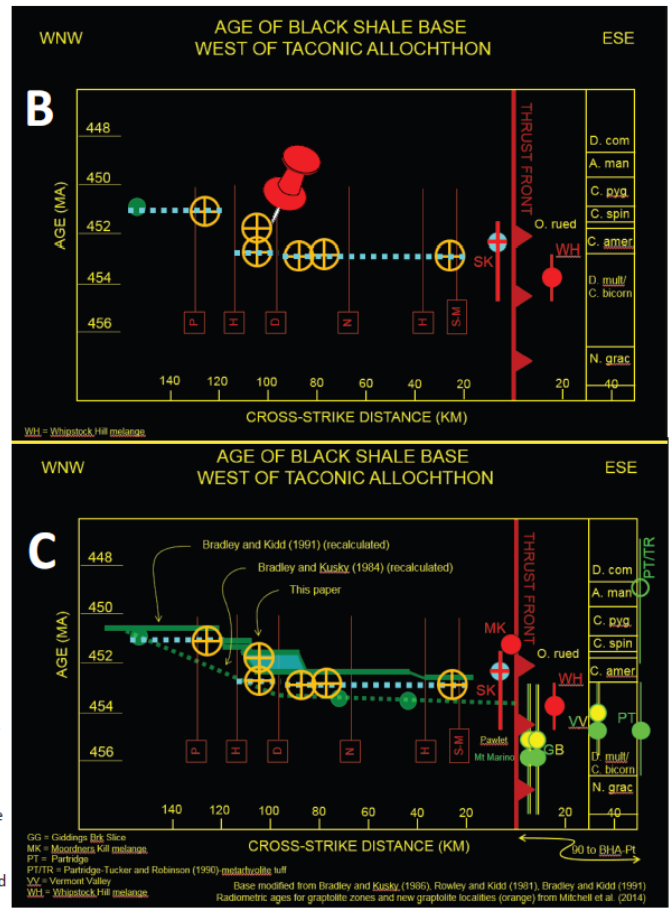
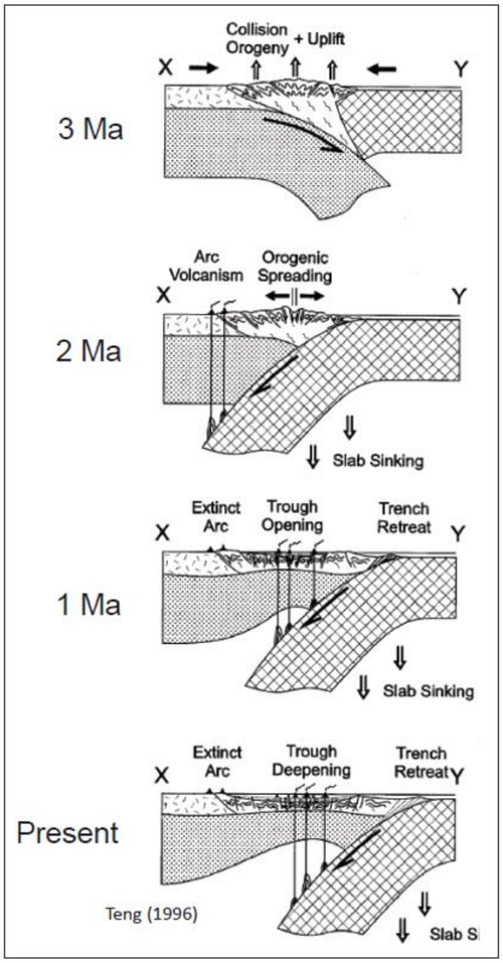
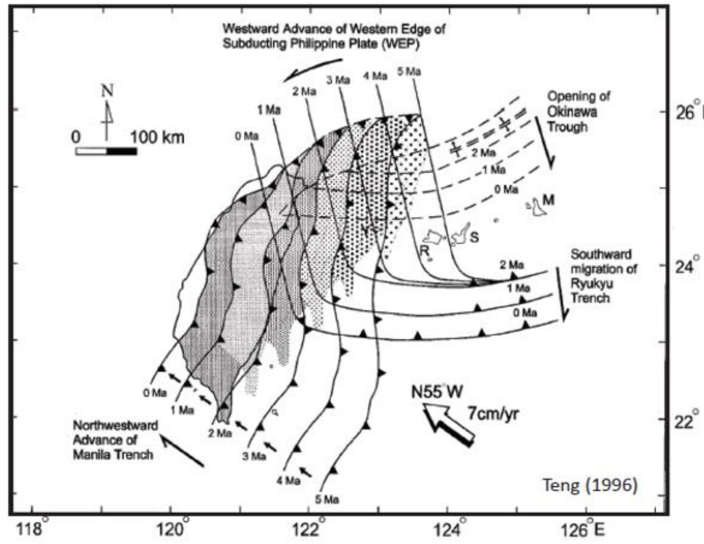


Figure 7. Utica Deposition in the Mohawk Valley Region.
A) Map of the Mohawk Valley region. Utica and overlying coarser clastics in buff. B&C) Chrono-stratigraphic cross-section from east of the Taconic Allochthon (blue in Fig. 7A) west-northwest to west of the Prospect Fault (Fig. 7a). Yellow circles indicate the locations of fingerprinted and dated ash layers integrated with graptolite studies (Mitchell et al. 2015) that reveal the age of the base of the Utica black shale. D) Model to explain the sharp change in the basal age of the Utica at ~ 100 km. The reactivated listric faults generally acted in concert east of the "pinned" western extent of the Iapetan-opening detachment at ~ 100 km. The Iapetan detachment is portrayed in the modifed upper panel from Rowley and Kidd (1981) and is shown reactivated during Taconic in the lower panel (e.g. Jacobi et al., 2003).





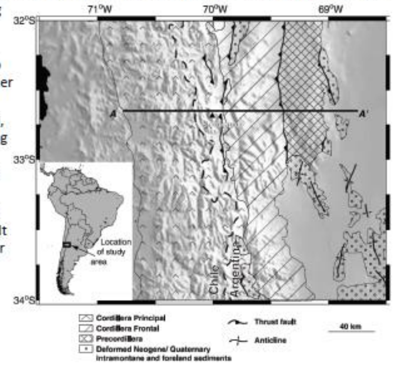
TAIWAN

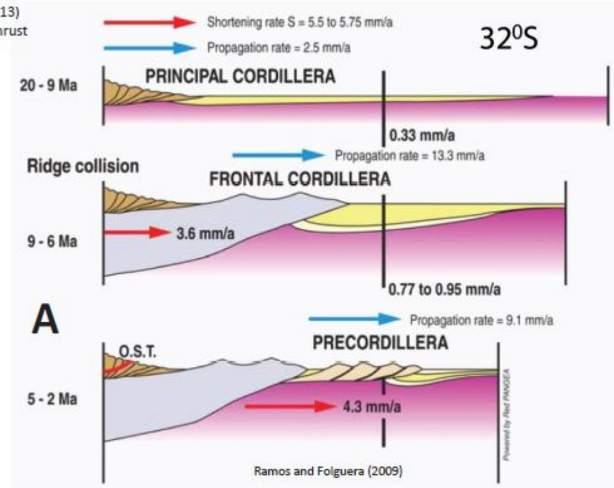
Figure 8. Tectonic Evolution of Taiwan, Involving Subduction Polarity Reversal, Trench Rollback, and Asthenospheric Upwelling (Teng, 1996).

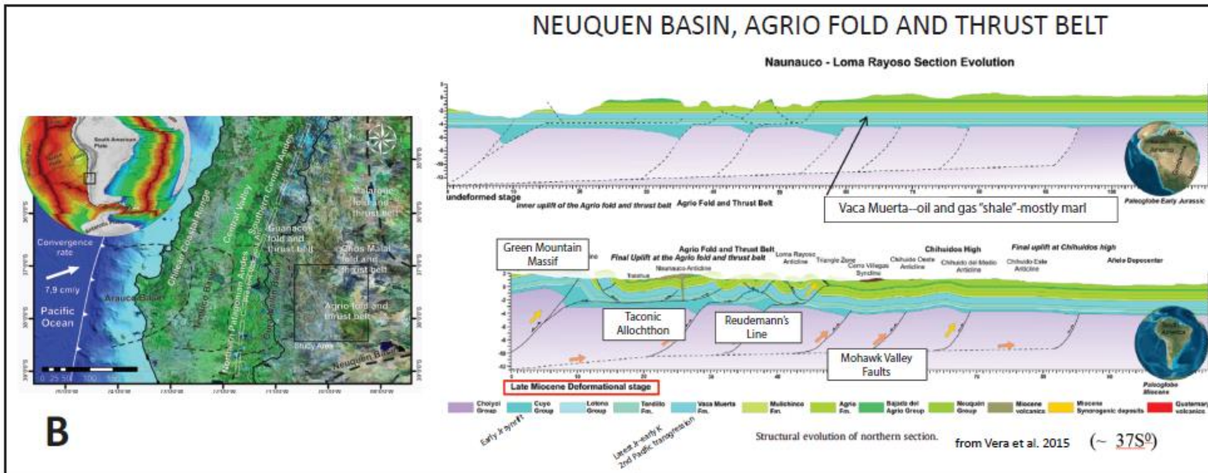
Figure 9. Andean Retroarc Thrust Belts As Analogs to the Syndepsitional Thrust Systems of the Utica in the Mohawk Valley Region

A) The retroarc foreland basin along the Andean margin at 32°S developed significantly during ridge collision with consequent intracontinental thrust block loading (intermediate panel); retroarc thrusting in the basin occured soon after (ca. 1 my) partly as a result of the high trench-normal convergence rates (Ramos and Folguera (2009). Indeed, Maloney et al. (2013) found that most compressional events along the Andean margin (including the fold and thrust belts east of the Altiplano-Puna Plateau in the central Andes) correlate with high trench-normal convergence rates of > 4 cm/yr.

B) The Andean retroarc Neuquen Basin at ~37⁰S appears to be an analog for the Utica basin. Fault systems that developed during continental break-up (detachment and listrics in the upper panel) were reactivated in several phases, including during Eocene anf the Micoene compressional events displayed in the lower panel. Basement involved thrusts accomodated shortening in the west, whereas suprastructure thrusts are common in the Agrio fold and thrust belt farther east (lower panel). Taken together (A and B), we have a tectonic analog for the evolution of the Utica Basin, as indciated by the Taconic tectonic elements labeled on the Agrio fold and thrust fault cross section in the lower panel.

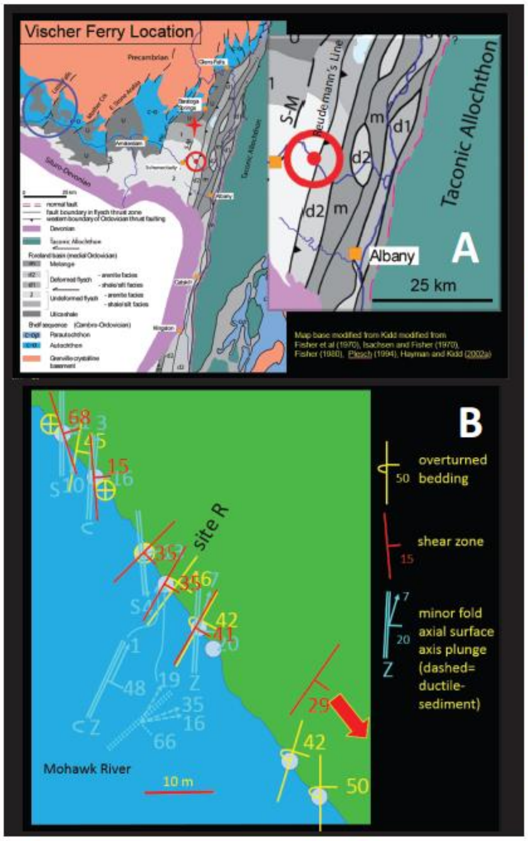






B

Figure 10. Syn-depositional Nappes and Thrusts in the Eastern Utica Basin of the Mohawk Valley: the Vischer Ferry Site



Reudemann's Line (Kidd, unpub; Fig. 10a) generally marks the western limit of recognized thrusts and melange zones that are assumed to be Taconic in age in the Schenectady/Normanskill/Austin Glen shales and greywackes. The Vischer Ferry site displays nappes, overturned bedding, developing scaly cleavage and ductile ("soft sediment") deformation of sandstones in thrust zones. Graptolites found in the sediments at Visher Ferry are of the Diplacanthograptus spiniferus Zone, which corresponds to sediment deposition between 451.6 and 450.9 Ma. The soft- sediment-involved thrusting indciates that the faulting occurred soon after deposition, i.e., Taconic. The quick transition from basin development to basin shortening is consistent with either Proposal 1 Model (collision with eastward subduction) or Proposal 2 Model (with westward subduction of a ridge). In the Proposal 2 Model, the basin subsidence resulted from basement thrust loading (as in Fig. 9a) and the Reudemann's Line/Vischer Ferry deformation resulted from shortening such as in Fig. 9b. A) Location and Geology Map of Reudemann's Line and Vischer Ferry.
B) Structure Map at Visher Ferry.
C, D) Thrust zone with ductile-sediment deformation.
E) Overturned bedding typical of Vischer Ferry east of the western thrust
F) Recumbant minor folds on a nappe verging west at site R in Fig. 10b.