ALONG-STRIKE PROPAGATION OF SLAB BREAKOFF AT THE END OF THE TACONIC OROGENY: A MODEL OF SHORTENING-EXTENSION TRANSITION ACCOMPANYING STRIKE-SLIP FAULTING 83-45

CHUL LIM* and WILLIAM S. F. KIDD, (Department of Earth and Atmospheric Sciences, University at Albany, 1400 Washington Ave., Albany, NY 12222) *: CL0250@csc.albany.edu

ABSTRACT

The breakoff of the subducted slab removes downward pull to switch the compressional stress in a collision zone to tensional stress, resulting in shortening structures in the collision zone being cut by younger normal faults. Lateral propagation of the slab bre akoff requires development of strike-slip cross faults to accommodate differential strains caused by migration of the marginal slab pull and the breakoff point. We illuminate late structures in the New York-Vermont-Quebec Taconic orogen in the context of a laterally propagating slab breakoff. The last shortening along reverse-motion veins in the Cohoes Melange is correlated with the late shortening along the Champlain thrust. The normal faults along the western boundary of Taconic Allochthon and the Mettawee Fault, and many small normal faults/veins in the melange were caused by the subducted slab breakoff. Timing of this regio nal extension is constrained to be immediately following the latest thrusting during the Caradocian and before the latest Silurian. The strike-slip cross faults/veins in the foreland zone resulted from the propagation of this slab-breakoff event. Develop ment of the reverse-motion veins marks conspicuous brittle deformation of the melange zones at the end of the Taconic shortening caused by the marginal slab pull. The reversal of subduction polarity provides a tectonic framework that requires the slab br eakoff. Propagation of the slab breakoff toward north at the end of Taconic convergence is supported by progressively later occurrence of the last shortening events in the same direction and oblique collision of the Laurentian margin with islan d arc(s).

INTRODUCTION

Rapid vertical uplift and lateral extension in some active convergence zones have been suggested to be a surface expression of detachment of subducting slabs, based on geological and geophysical observations (McCaffrey et al., 1985; Charlton, 1991; Chate lain et al., 1992). A slab breakoff marked by seismicity gap and attenuation of seismic waves (Isacks and Molnar, 1969; Chatelain et al., 1992; Wortel and Spakman, 1992) can occur at various mantle depths as a function of subduction rate (Davies and von Blanckenburg, 1995), and is an event that must occur during reversal of subduction polarity in arc-continent collision zones (van Staal et al., 1998). Slab breakoff also has been invoked as a possible mechanism for recycling of continental crustal materials into the mantle, and as a mechanism for syn- to post-collisional magmatism and metamorphism (Davies and von Blanckenburg, 1995; Hildebrand and Bowring, 1999). The slab breakoff can propagate along strike (Wortel and Spakman, 1992). Shear stress near the tip of tear point is of sufficient magnitude to cause further lateral migration of the tear at velocities of centimeters to meters per year (Yoshioka and Wortel, 1995). The lateral propagation of slab breakoff may be reflected in corresponding changes at the surface such as an orogen-parallel component of depocenter shifts, rebound of the orogen, and along-arc migration of magmatism (Meulenkamp et al., 1996; Mason et al., 1998; van der Meulen et al., 1999).

We discuss structures in the foreland zone of the Taconic orogen from eastern New York through western Vermont to Quebec in the context of a model of slab breakoff that propagates along strike below converging lithospheres, with consequent systematic changes in local stresses and related structures. Characteristics of and age constraints on newly recognized structures are related to changes in strain occurring during the slab-breakoff process.

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GEOLOGIC SETTING OF THE TACONIC OROGEN

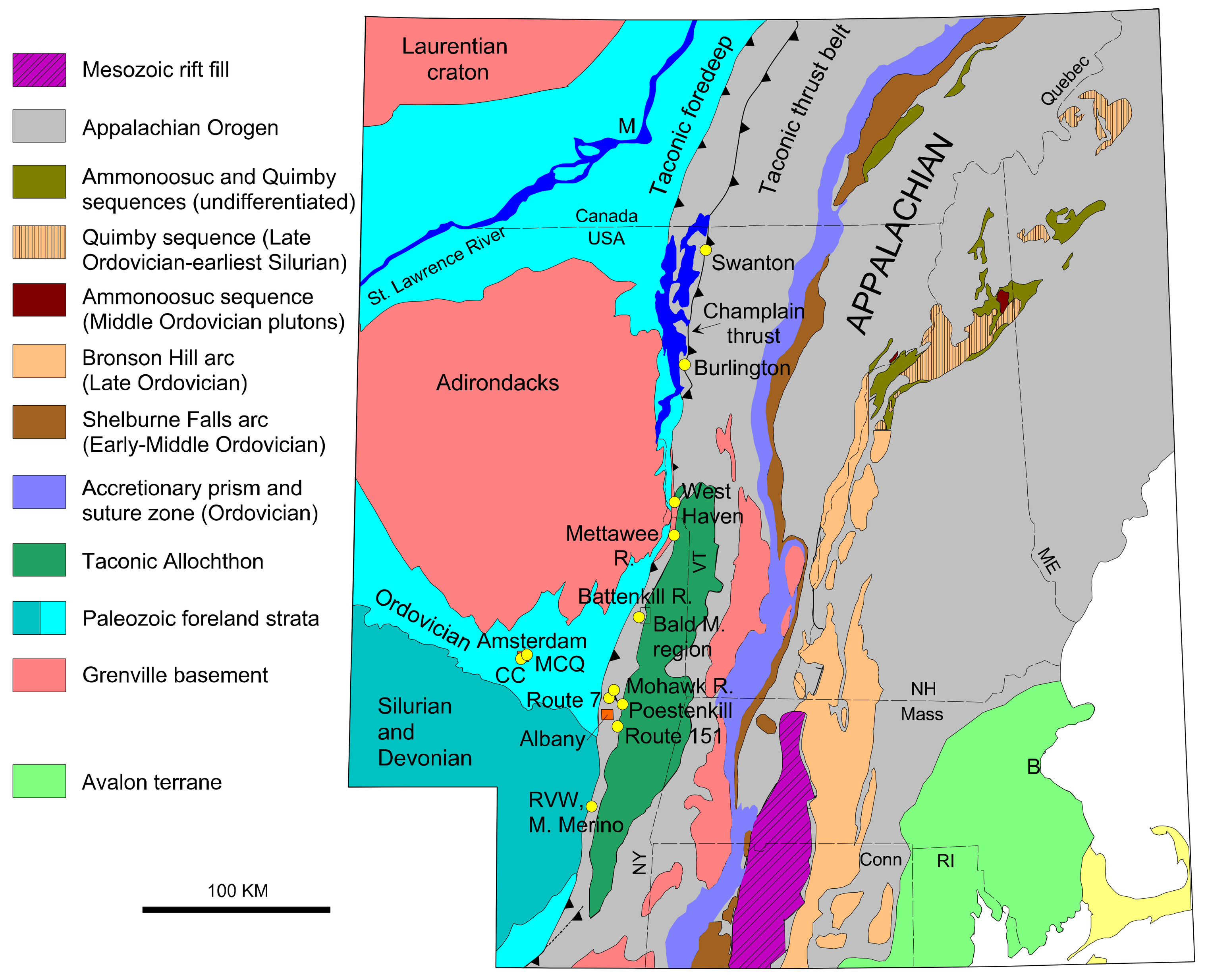


Fig. 1. CC: Chuctanunda Creek, MCQ: Manny Corners Quarry, RVW: Rip Van Winkle Bridge, B: Boston, M: Montreal.

THE LATE STRUCTURES IN THE TACONIC OROGEN

I. Reverse- or Normal-Motion Veins/Faults in the Taconic Melange in Eastern New York (after Lim et al. (2005))

Fig. 2

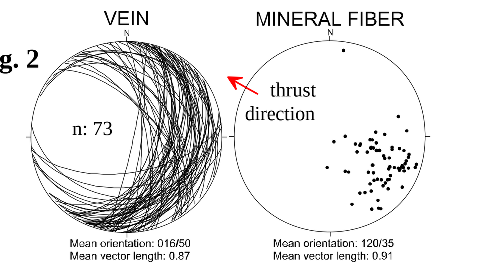


Fig. 3

The reverse- and normal-motion veins are correlated with the Champlain thrust and the Mettawee Fault in western Vermont, respectively.

The western margin of Taconic orogen was subject to

a regional extension following the last thrusting

based on

(1) the cross-cutting relationships of veins and faults (Fig. 3)

(2) fluid inclusion data

(3) restriction of the veins to Ordovician and older rocks

(4) restriction of normal-motion veins to the melange zone.

II. The Western Bounding Faults of the Taconic Allochthon

Fig. 4. Poestenkill Falls, Troy

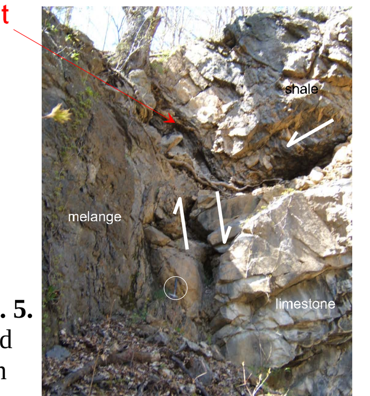
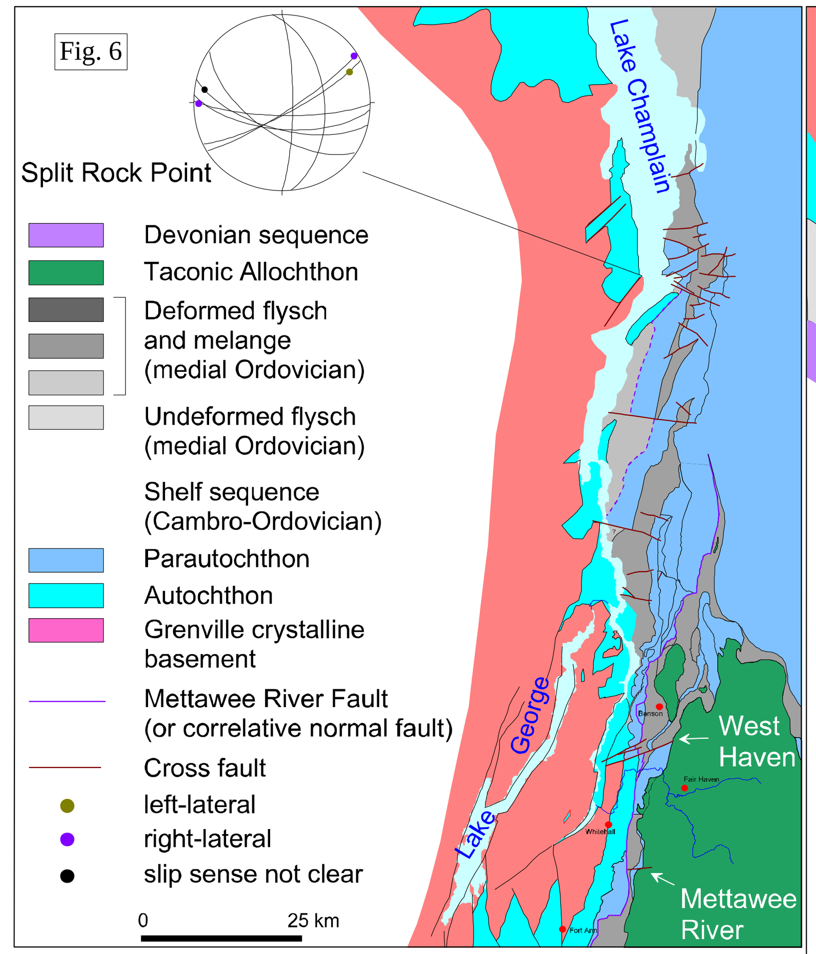


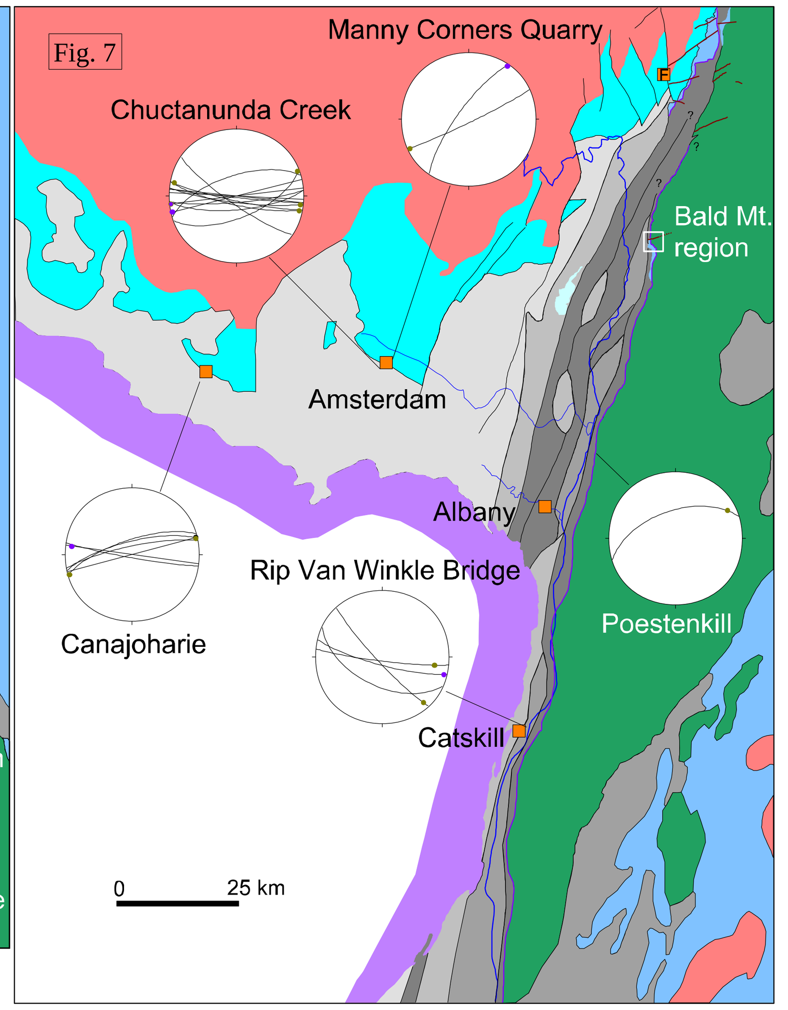
Fig. 5. Bald Mtn Quarry

III. Strike-Slip Cross Faults

1. Northern Map



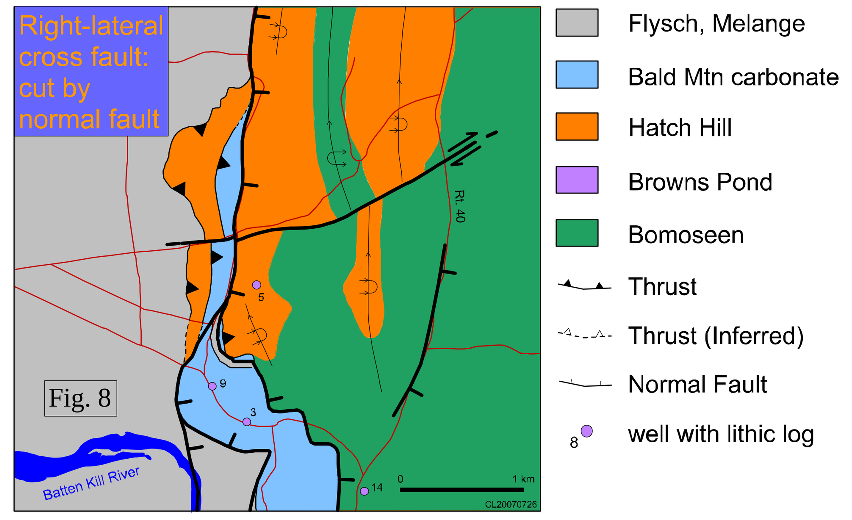
2. Southern Map



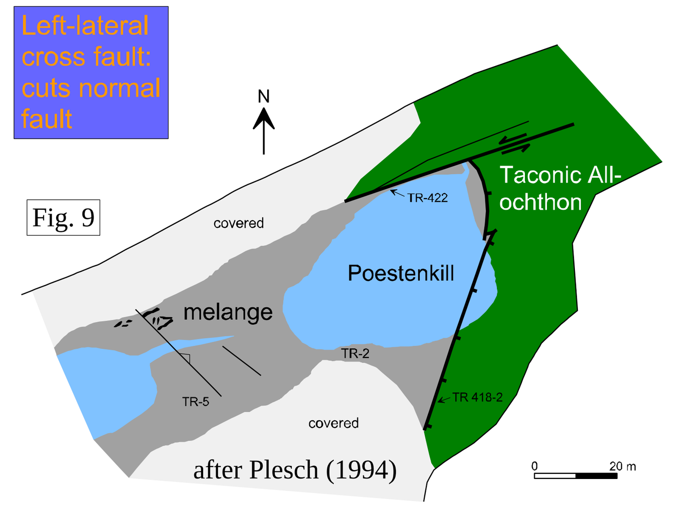
3. Quebec (Faure et al., 2004)

4. Detailed Maps and Ages of the Strike-Slip Cross Faults

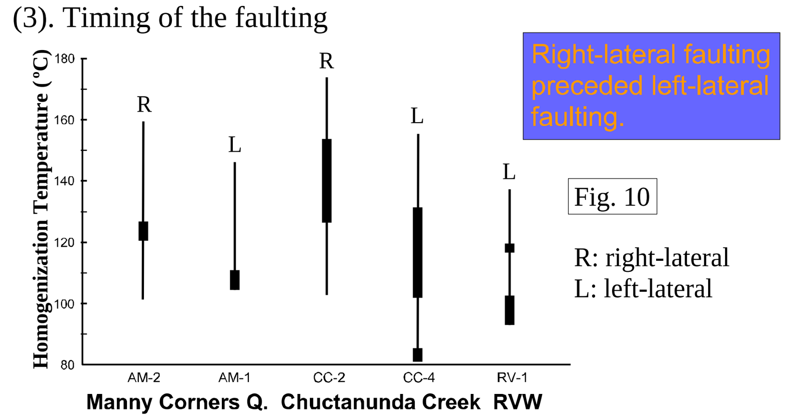
(1). The Bald Mountain region



(2). Poestenkill Falls



(3). Timing of the faulting

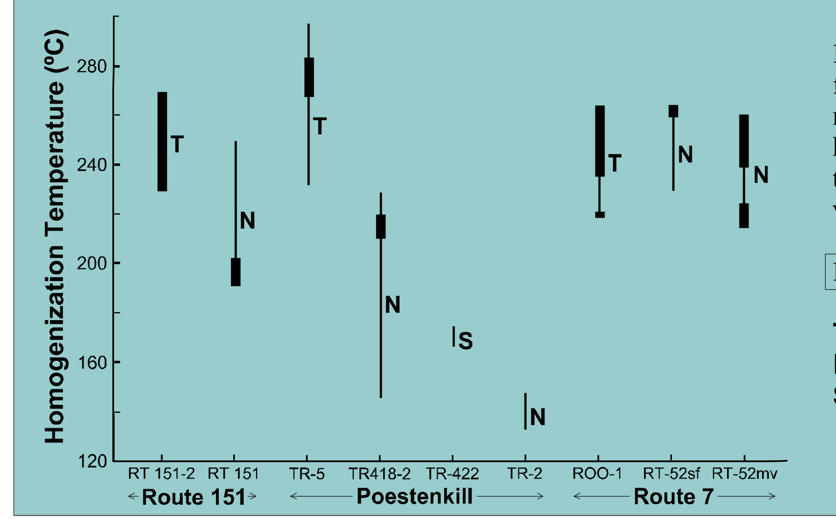


Right-lateral cross faulting before extension followed by left-lateral faulting during extension

➔ Migration of marginal slab pull coupled with the tear point following behind.

➔ The strike-slip cross faults formed as **accommodation structures from differential motions caused by the propagation of slab-breakoff.**

Cooling of the Vein-forming Fluids with Time



In general, older veins (inferred from cross-cutting relationships) precipitated from higher-temperature fluids than the younger (cross-cutting) veins in the same outcrop.

Fig. 11

T: reverse-motion vein
N: normal-motion vein
S: strike-slip vein (left-lateral)

DISCUSSION

I. Significance of the Taconic Vein System in the Melange Zones

The reverse-motion veins consistently cross-cut the melange cleavages and are not folded nor boudinaged. This suggests:

1. They formed following the end of major development of the melange zones.
2. The melange zones (apparently abruptly) became brittle to allow development of many thrusts (reverse-motion veins).
3. The brittle deformation requires a sudden increase of shortening rate at the end of the Taconic shortening event.

➔ Possibility of **Marginal Slab Pull.**

II. Reversal of Subduction Polarity

In the Taconic orogen of the northeastern US, occurrence of late-stage convergent volcano-intrusive sequences in addition to older arc sequences (Fig. 1; Tucker and Robinson, 1990; Karabinos et al., 1998; Moench and Aleinikoff, 2002) suggests a reversal of subduction polarity during the Taconic collision.

➔ The reversal of subduction polarity requires **slab breakoff.**

III. Along-Strike Propagation of the Slab Breakoff

The northward decrease of homogenization temperatures of fluid inclusions in the reverse-motion veins (Fig. 12) is interpreted to be a result of progressively later occurrence of the last shortening events toward the north.

➔ If the convergence was terminated by the slab-breakoff, the diachronous switch from the last shortening (marginal pull) to extension can be a consequence of **the northward propagation of the slab-breakoff event.**

The local Ordovician arc-continent collision was oblique, starting earlier at the New York promontory and being progressively later to the Quebec reentrant (Bradley, 1989).

➔ The continental lithosphere boundary at the New York promontory must have been subducted deeper (or sooner to a given depth), and would be **the most plausible site for the slab-breakoff to start** (Davies and von Blanckenburg, 1995); once initiated, it propagated northward to the Quebec reentrant.

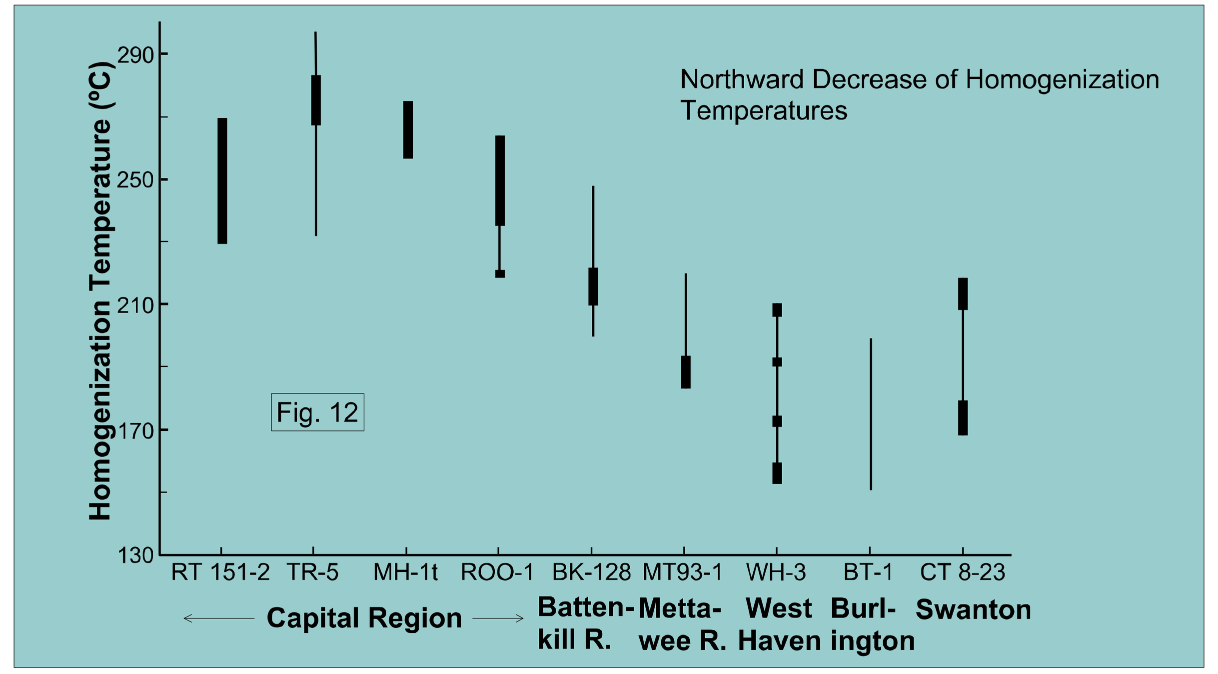


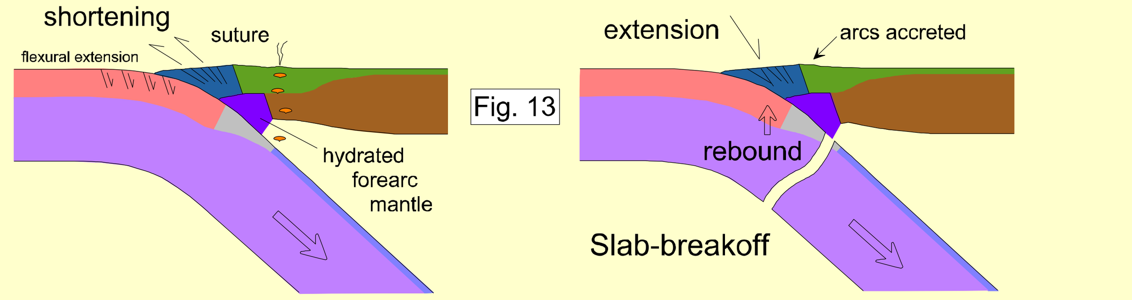
Table 1. Comparison of model events with the late Taconic structures

Sequence	Model event	Natural example
1	right-lateral strike-slip cross faults form	- right-lateral cross fault in the Bald Mountain region, dextral-motion veins near Amsterdam and Canajoharie.
2	brief and rapid shortening.	- reverse-motion veins from the Capital Region (New York) to Swanton (Vermont), see Lim et al. (2005).
3	The regional extension starts.	- normal faults/veins in the Bald Mountain region, the Capital region and Mount Merino (Lim et al., 2005), Mettawee Fault.
4	Left-lateral strike-slip cross faults form.	- strike-slip fault (vein) in Poestenkill, sinistral-motion veins near Amsterdam and Canajoharie.
5	Right-lateral strike-slip cross faults form.	- a right-lateral cross fault near West Haven.

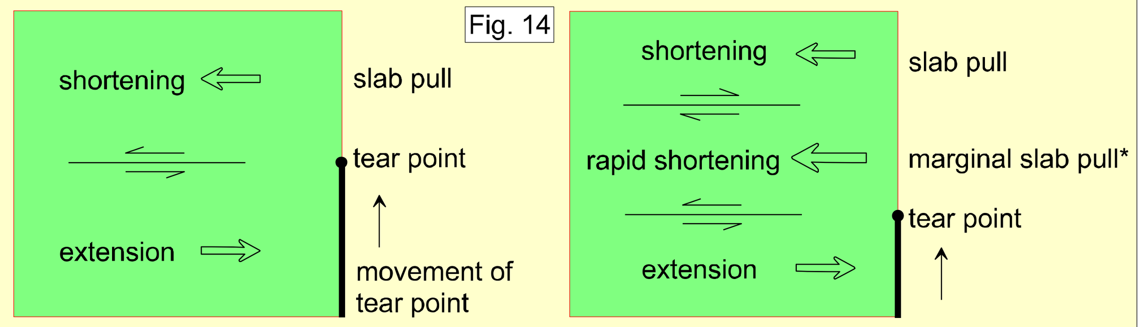
THE SLAB-BREAKOFF MODEL

Consequence and Process of the Slab-Breakoff

1. Regional Extension

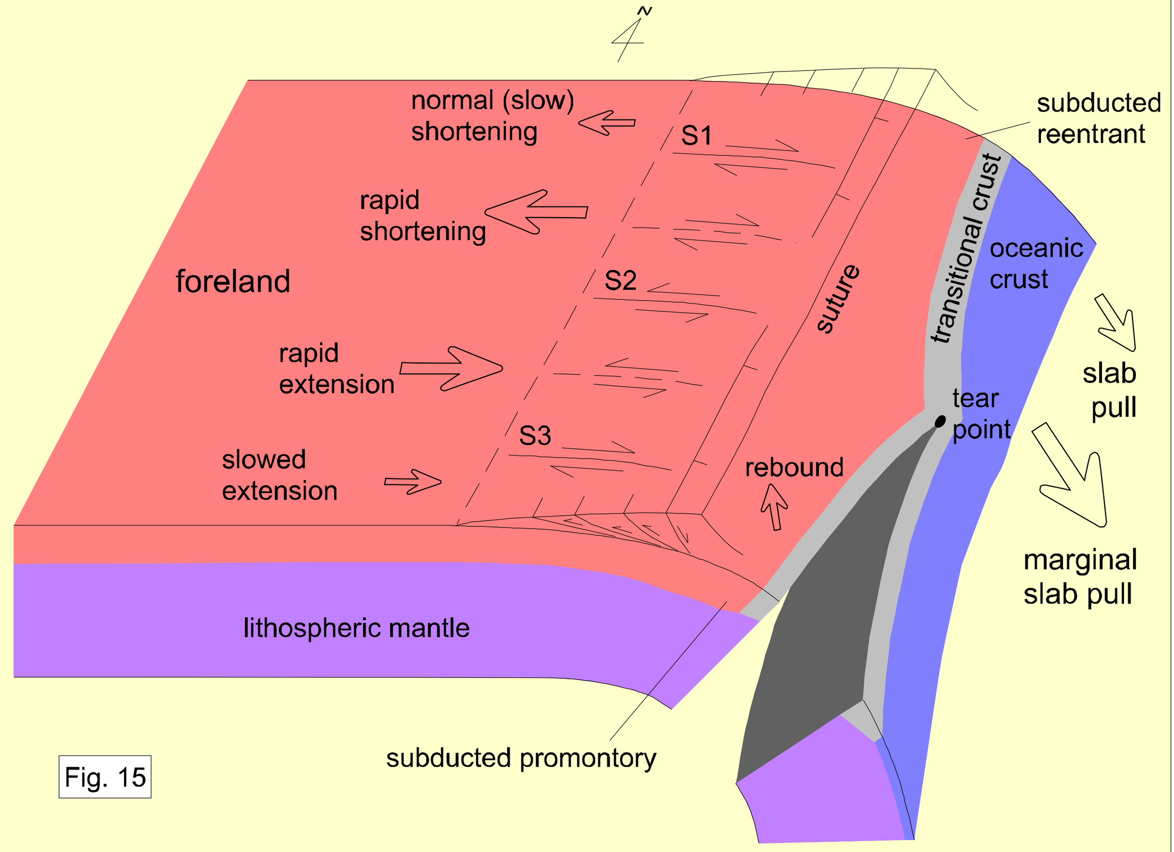


2. Strike-Slip Cross Faulting



***Marginal slab pull:** As long as the slab breakoff does not proceed to completion, the pull of the whole hanging slab is concentrated around the tear point, resulting in locally higher stresses over the untorn portion adjacent to the tear point (Wortel and Spakman, 1992; Yoshioka and Wortel, 1995).

3. Along-Strike Propagation of the Slab-Breakoff.



CONCLUSIONS

Recently recognized late structures of the margin of the Taconic orogen in New York and Vermont match well the structures that can be related to a propagating slab-breakoff model. We suggest that the reverse-motion veins in the Taconic melange reflects a brief episode of higher strain rate caused by the effect of localized marginal slab pull. The east-downthrow normal fault marking the western boundary of the Taconic Allochthon, and the Mettawee Fault, as well as many small normal faults/veins in the Cohoes Melange were caused by the subducted slab-breakoff at the end of the Taconic orogenic event. The reversal of subduction polarity at the end of the Taconic collision also requires breakoff of the eastward-subducted slab. The decrease toward the north of homogenization temperatures of fluid inclusions in the reverse-motion veins resu lted from progressively later occurrence of the last shortening events (marginal pull) toward the north. The geometry and regional pattern of subsidence of the Laurentian continental margin are also consistent with the slab-breakoff propagating toward the north. Distribution and slip sense of the strike -slip cross faults/veins in the western margin of the New York-Vermont-Quebec Taconic orogen and foreland also can be interpreted in the context of differential strain accommodating the laterally-propagating slab-breakoff (Fig. 14, 15).

We propose a model of structures produced by major change of stress field during laterally propagating slab breakoff. At the slab tear-point, the compressional stress over collision zone switches to tensional stress in response to the rapid rebound of the partially-subducted continental margin, resulting in the shortening structures cut by many normal faults. Lateral propagation of the slab breakoff explains strike-slip cross faults formed as accommodation structures at the boundaries of contrasting areas of shortening and extensional strains.