Fault propagation, exhumation and triangle zones in analog models of thrust wedges: influence of syntectonic erosion and sedimentation

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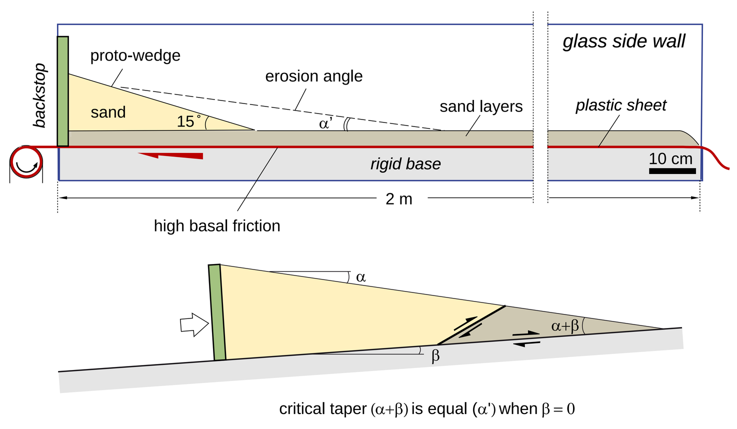
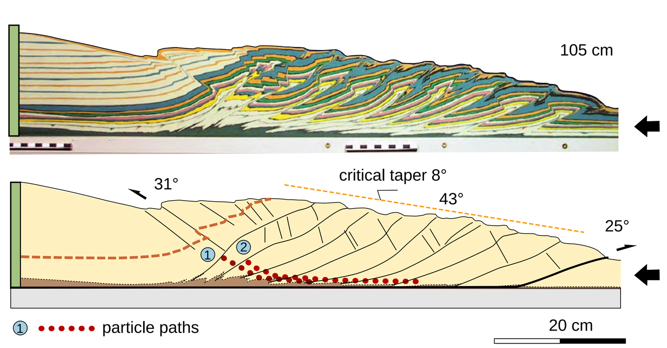
Structural Geology and Tectonic Forum 2012
Williamstown, MA June 14-16, 2012

Scheme of the experimental device



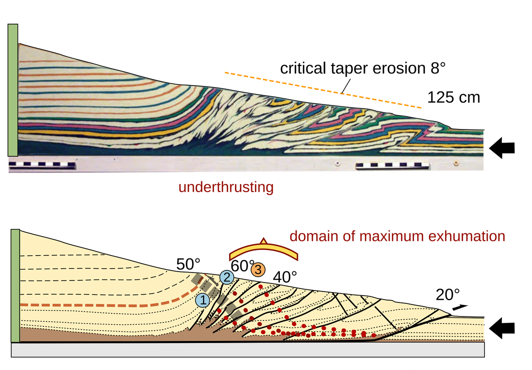
Critical taper angle (α+β) composed of the dip angle of basal detachment β and the taper angle α determines the geometry of a thrust wedge, modified after Davis et al. (1983). Critical taper angle of our model wedges is equal to the imposed erosional slope (α′) because basal detachment is horizontal.

MW1. No décollements, no erosion



No exhumation is observed. The wedge slope 8° (e) represents the critical accreting taper angle for the thrust wedges with high basal friction.

MW2. No décollements, erosion 8°



The thrust wedge retains the same geometry through shortening. Exhumation of basal layers is observed at the rear part of the wedge at the end of shortening.

nalog sandbox modeling is used to study the impact of syntectonic erosion and sedimentation on fault geometry and exhumation rates in thrust wedges with one and two frictional décollement levels. The diversity of exhumation patterns in eroded thrust wedges is controlled by the mode of fault propagation, depending on the basal friction (high or low).

In the thrust wedges with one and two décollements, different accretion mechanisms are activated depending on interactions between surface processes and wedge mechanics: frontal accretion, backthrusting, underthrusting and underplating due to décollement-induced duplex formation at depth. These mechanisms may function simultaneously, being located at different parts across the wedge.

Presence of one décollement in the accreted series allows underplating of thrust units developing an anticlinal stack, whose growth and location is favored by erosion. The cover layers are nearly completely eroded above the antiformal stack and form the synformal klippe in frontal part of the thrust wedge.

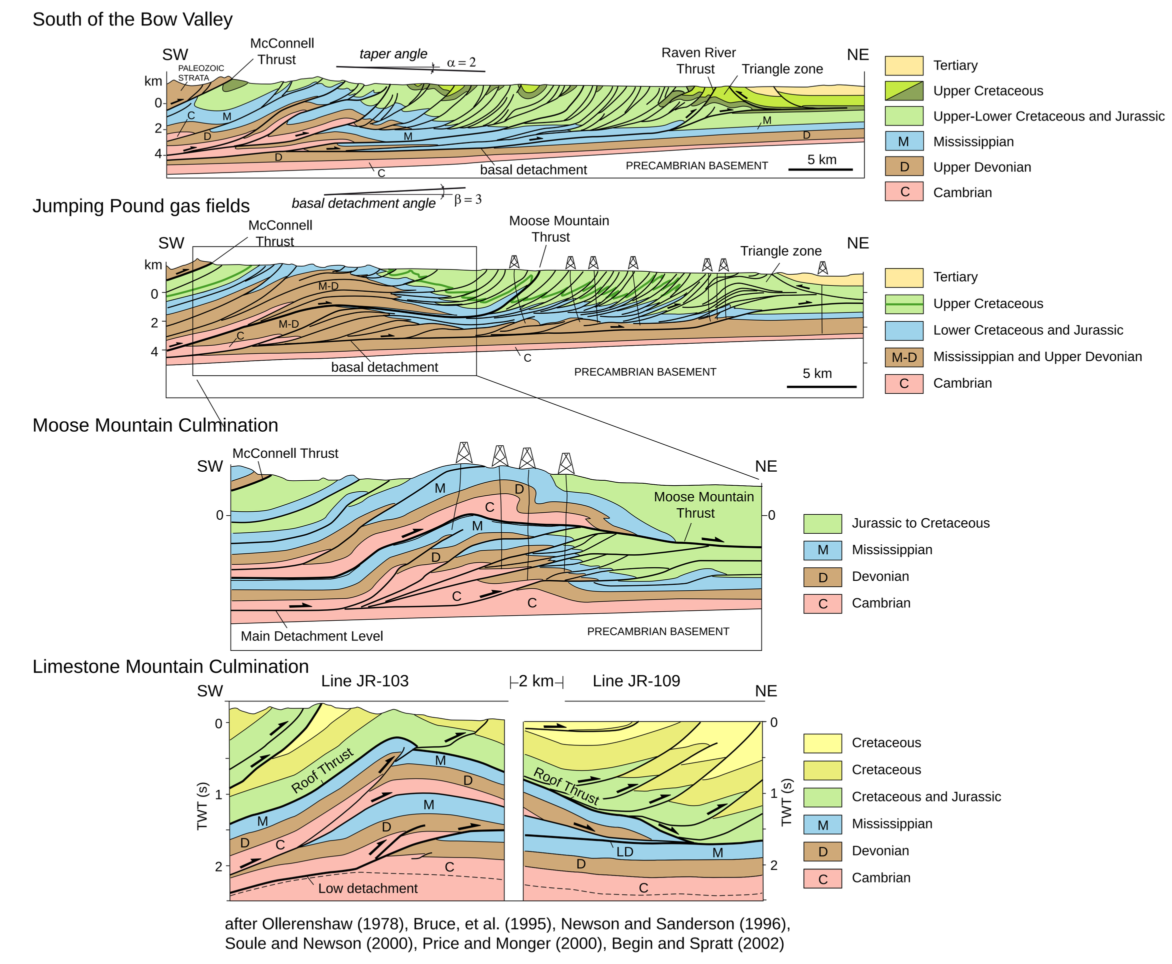
Erosion limits the forward propagation of thrust wedges and favors the underthrusting of basal layers allowing duplex formation. At the advanced stages of erosion, the development of major backthrusts is observed in the thrust wedges without or with one décollement, but no backthrusts is formed in the wedges with two décollements. Variations in the erosion taper lead to changes in duplex geometry and exhumation rate in the thrust wedges with two décollements.

Syntectonic sedimentation induces forward propagation of flat detachments, resulting in the formation of a piggyback basin.

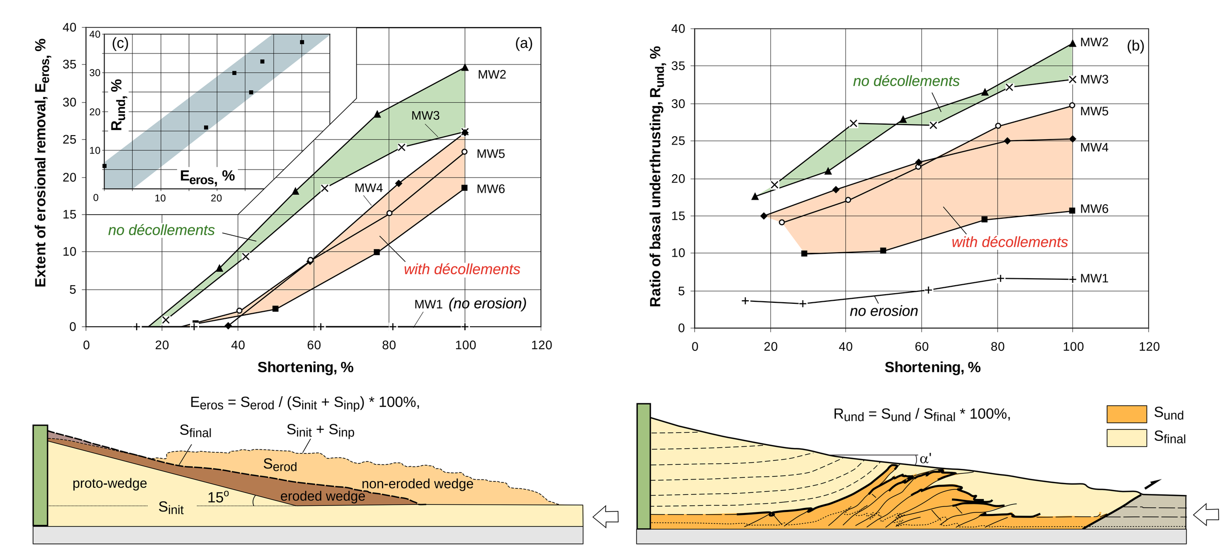
Syntectonic erosion and sedimentation acting simultaneously on the thrust wedge promote formation of a triangle zone between the frontal imbricate faults of the wedge and the foreland basin.

The experimental results support the observations on structural evolution and erosion in the Alberta Foothills of the Canadian Rockies and in the Quebec Appalachians.

Structural cross-section across the southern Alberta Foothills

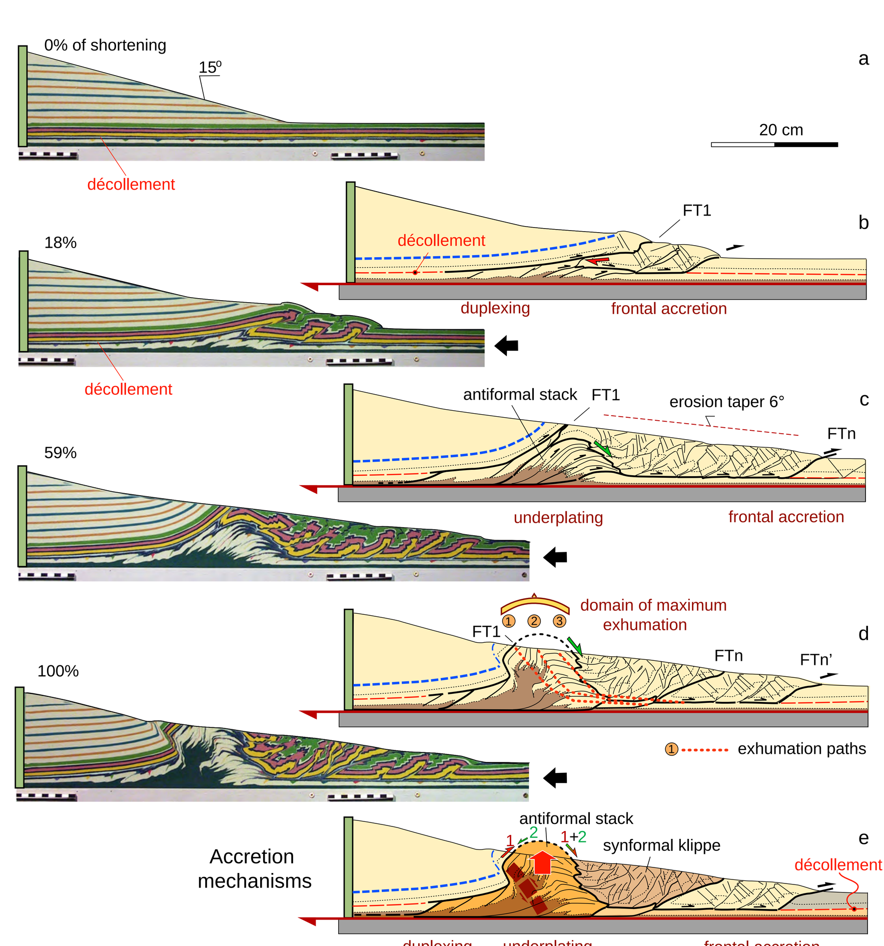


after Ollerenshaw (1978), Bruce, et al. (1995), Newson and Sanderson (1996), Soule and Newson (2000), Price and Monger (2000), Begin and Spratt (2002)



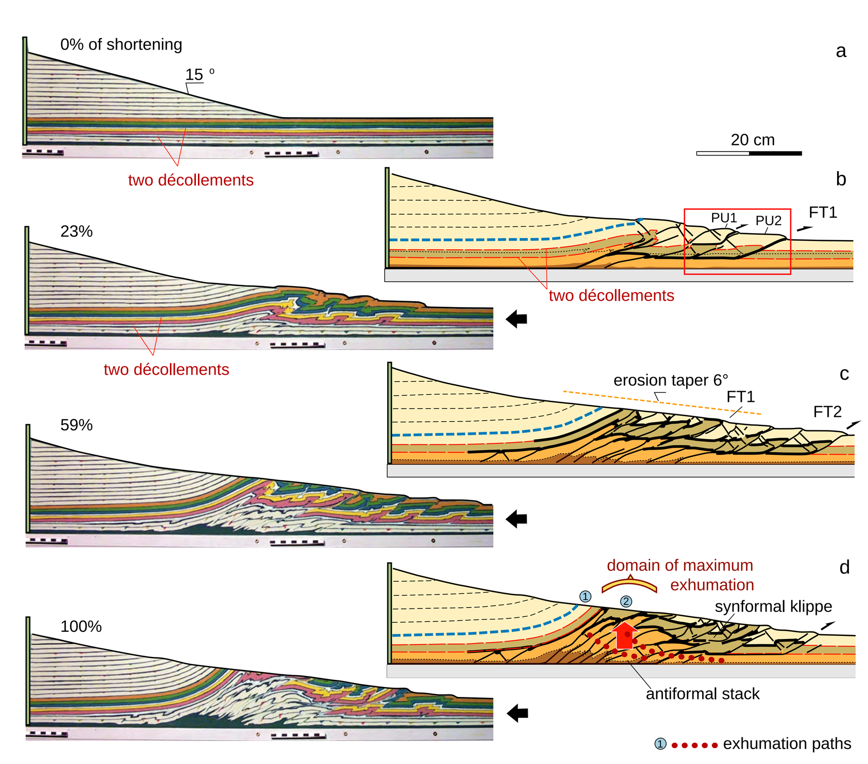
(a) Proportions of initial (Sinit), eroded (Serod), and final (Sfinal) areas in model wedges used to calculate extent of erosional removal (Eeros). Serod=Sinit+Sinp−Sfinal. (b) Ratio of basal underplating (Rund) calculated as a ratio of the area of basal layers (Sund) with respect to final area (Sfinal) in model wedges. Sinit, Sfinal and Sund are measured from digitized photos of the model wedges. Sinp is calculated from experimental parameters.

MW4. One décollement, erosion 6°



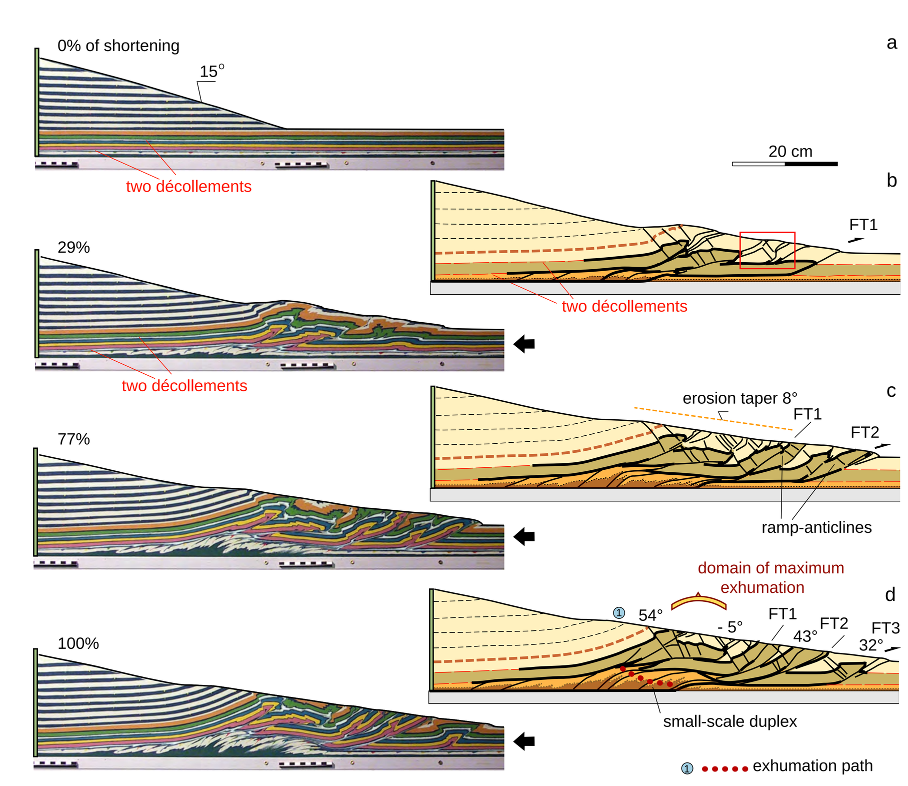
Exhumation of basal layers is observed in the dome-like antiformal stack at the rear of the wedge at the end of shortening (d). Thrust faults steeply plunge down the section at the frontal part of the growing antiformal stack (c–d). The cover layers above décollement are completely detached from the basal layers and compressed in synformal klippe (c–e).

MW5. Two décollements, erosion 6°



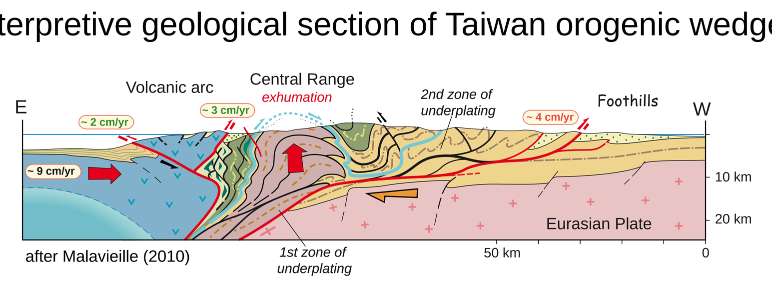
The independent system of thrusts develops above each décollement (red square). The basal layers below the lower décollement form antiformal stack growing through shortening (b–d) but they are not exhumed (d). The cover layers above the lower décollement are nearly completely eroded above the stack (d). Thrust faults steeply plunge down the section at the frontal part of the growing antiformal stack (d). The imposition of erosion taper with lower (6°) angle than the critical value (8°) in the models with décollements promoted formation of antiformal stack with high extent of exhumation.

MW6. Two décollements, erosion 8°



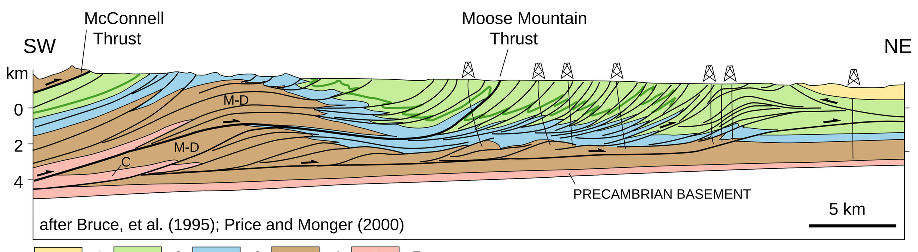
Thrusts are frequently independent below and above the upper décollement (red square). The basal layers below the lower décollement form small-scale normal duplex slightly growing through shortening (b–d). Basal material is never exhumed (d). The cover layers form individual ramp-anticlines (c–d). Thrust faults are slightly inclined down the section at the frontal part of the growing basal duplex (d). Only cover layers above the upper décollement are eroded above the duplex (d). The 8° erosion profile (equal to critical slope) provided formation of individual ramp-anticlines in the upper wedge above the décollement and small scale normal duplex below it with low amount of basal underplating.

Interpretive geological section of Taiwan orogenic wedge



after Malavieille (2010)

Simplified structural section across Jumping Pound gas fields



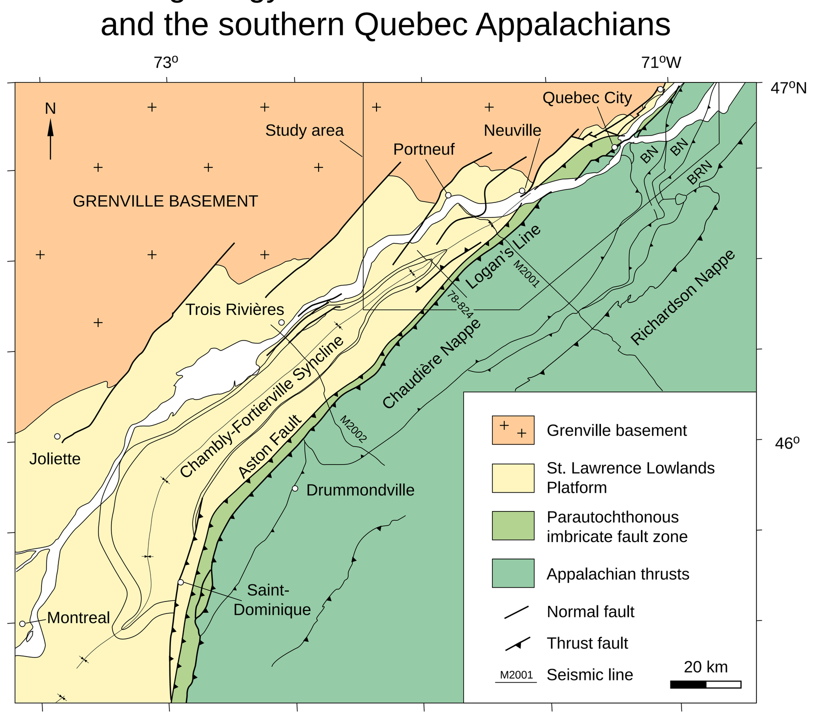
after Bruce, et al. (1995); Price and Monger (2000)

1, Tertiary; 2, Upper Cretaceous; 3, Lower Cretaceous and Jurassic; 4, Mississippian and Upper Devonian; and 5, Cambrian strata.

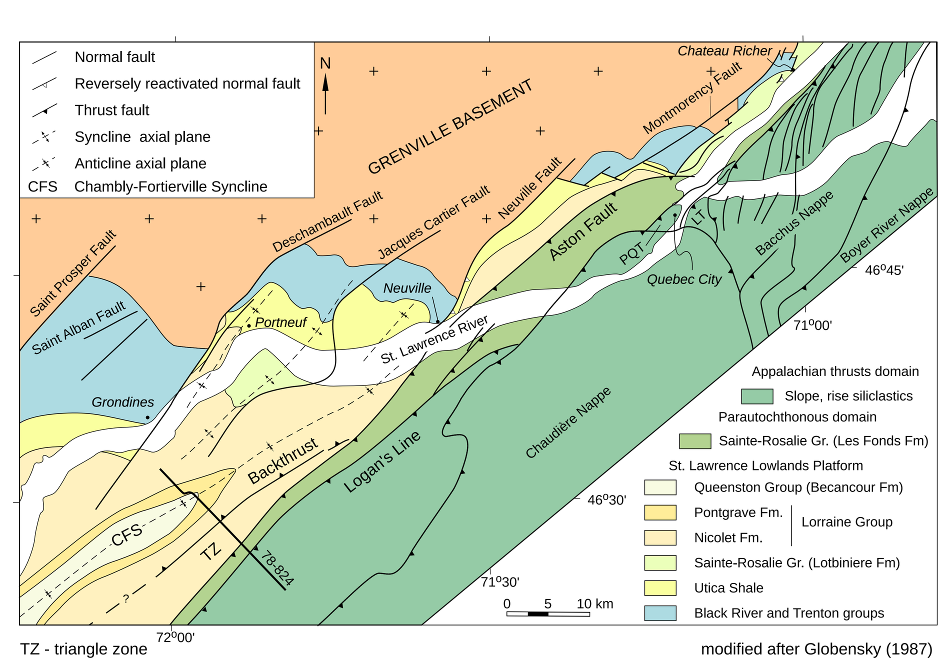
Interactions between surface processes and wedge mechanics have important consequences on the structure and evolution of foreland thrust belts. Different accretion mechanisms are thus combined to account for wedge growth: frontal accretion, backthrusting, underthrusting and underplating due to décollement induced duplex formation at depth. These mechanisms may function simultaneously, being located at different parts across the wedge.

Our experiments clearly reflect these complex feedback mechanisms. Addition of erosion limits thrust wedge forward propagation and thickening. The higher rate of erosion leads to higher extent of exhumation of basal material. Variations in erosion slopes led in changes of fault kinematics and of the extent of basal material exhumation.

General geology of the St. Lawrence Lowlands and the southern Quebec Appalachians

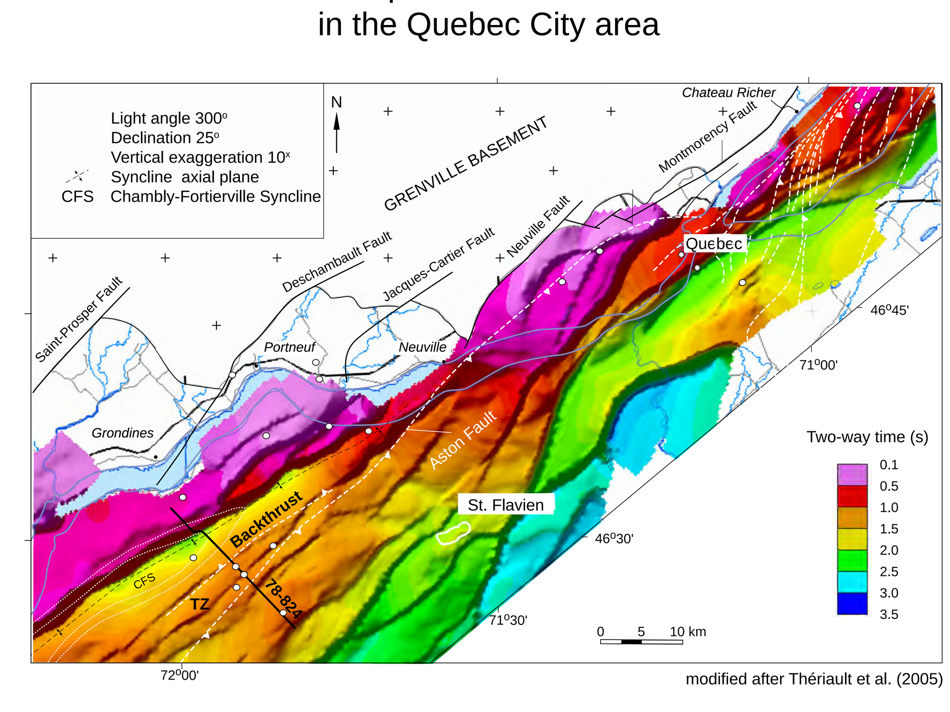


Geological map of the Quebec City area



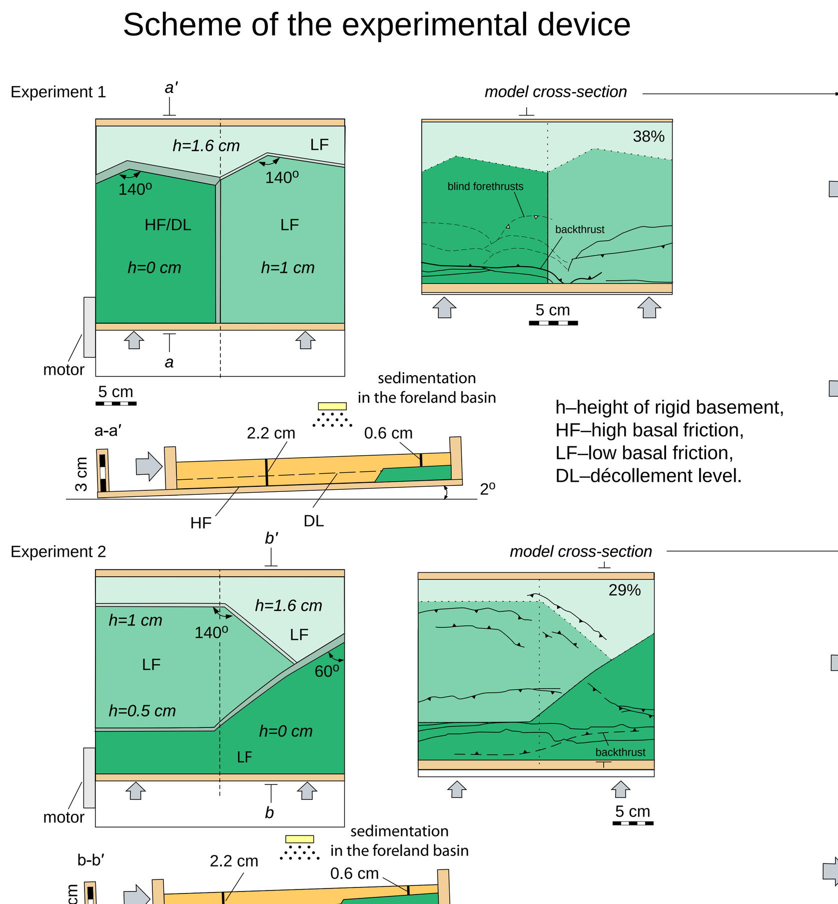
modified after Globensky (1987)

Time structure map of the Precambrian basement in the Quebec City area



modified after Thériault et al. (2005)

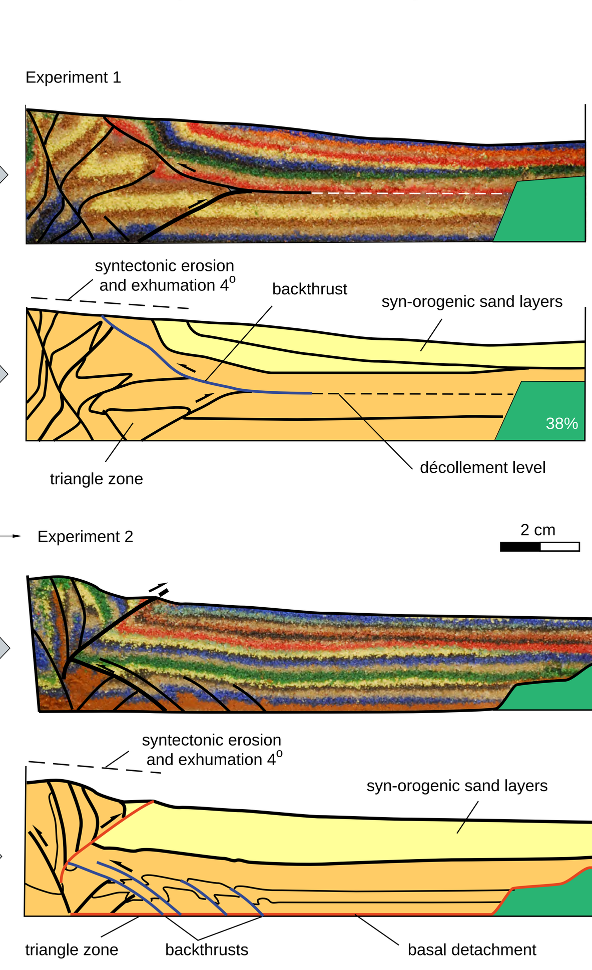
Scheme of the experimental device



h–height of rigid basement,
HF–high basal friction,
LF–low basal friction,
DL–décollement level.

Variations in the initial thickness of sand layers are controlled by frontal and lateral rigid escarpments parallel or oblique to the shortening directions, which were introduced at the base of the models. Their geometry mimics the structure of the Grenville basement in the Quebec City area.

Experiments with syntectonic sedimentation and erosion



Note deflection in plan view of frontal thrust against the deep basement escarpment and development of backthrusts and triangle zone at the rear of the thrust wedge.

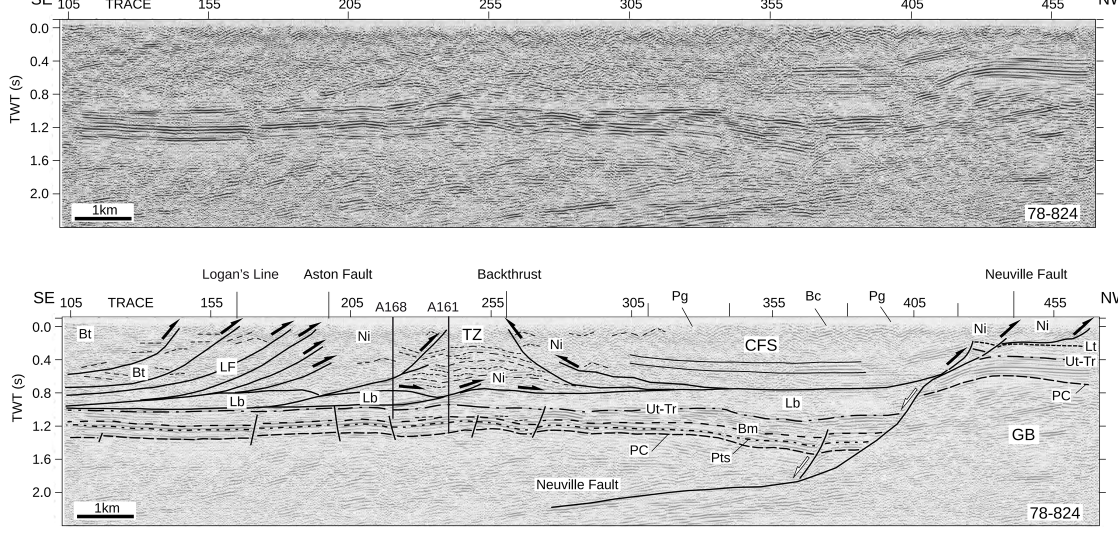
Syntectonic sedimentation in the foreland of the fold-and-thrust belt changed the dynamics of the tectonic wedge and favoured the activation of weak décollement layers at the base or within the cover. This led to the forward propagation of detachments and induced the development of piggyback basins.

Syntectonic erosion retarded forward propagation of the wedge, enhanced material transport across the wedge, and focused internal deformation and exhumation close to the backstop.

Syntectonic erosion and sedimentation together affected the thrust wedge kinematics; a series of backthrusts and/or triangle zones developed at the rear of the wedge.

Deflection and rotation of frontal detachments was influenced by the presence of an oblique, steep basement escarpment in front of the growing wedge, by gradual changes of sand layer thickness across the ramp and by differential slip along the basal detachment. Deflection is produced by differential forward motion of the hanging wall along the fault strike and a counter-clockwise rotation about a vertical axis.

Upper crustal structure across the Appalachian front



Re-interpreted seismic line across the Appalachian front showing location of the triangle zone (TZ).

ACKNOWLEDGMENTS

One part of the present study was supported by a French MENRT grant to Elena Konstantinovskaya to fund the Associate Professor position in Montpellier (2000–2003). Another part of the study was realized in the INRS-ETE laboratory for physical simulations, which was funded by a Canada Foundation Innovation, Ministère de l'Education, de Loisir et du Sport grant, with contribution from INRS-ETE, BEG (University of Texas at Austin), Sun Microsystems, Seismic Microtechnology and Norsar to Lyal Harris. Open File seismic lines and well data from the Ministère des Ressources naturelles et de la Faune, Quebec, formed a basis for regional geological studies.

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