Centrifuge modeling of the effects of pluton emplacement on shearing and folding in transtensional shear zones: Applications to the Carthage Colton Shear, Adirondack Mountains, New York State

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ABSTRACT

Centrifuge modeling of the emplacement of analog granitic magma in transtensional environments clearly show that the magma bodies migrate into existing fault/shear zones and boudin necks. In the absence of these structures analog magma bodies beneath competent horizons migrated laterally with little to no vertical migration. Preexisting faults reactivated during tension or transtension provided preferred pathways for diapiric rise of lower density and viscosity putty simulating magma which facilitated fault slip in our models. It appears that the lower density and lower viscosity material, once drawn into the active fault, acted as a lubricant accelerating slip which, in turn, resulted in a marked flattening of the fault surface during extension. Along strike variations in slip caused by differential lubrication of the fault surface resulted in folding of the fault surface during transtension even at low strains (24%). Continued extension rapidly led to formation of accommodation faults between sections with marked differences in slip. In the Adirondack Mountains of northern New York State, Proterozic (Grenville-aged) granitic magmas of the Lyon Mountain Series spatially associated and contemporaneous with transtensional slip along the folded Carthage Colton Shear (CCSZ) provide a natural application of our model results. Fold axis orientations parallel stretching lineations in the zone suggesting that folding of the CCSZ occurred while the shear zone was active. Based on our observations from the analog models, the injection of granitic magmas into the active shear zone may have facilitated slip along segments where these magmas are present. Along strike variations in the volume of magma being drawn into the shear zone is interpreted to have produced differential lubrication of the shear zone leading to its folding comparable to analog models. Detailed mapping of the distribution of Lyon Mountain granite in and adjacent to the CCSZ needs to be done in order to test this hypothesis.

METHODS

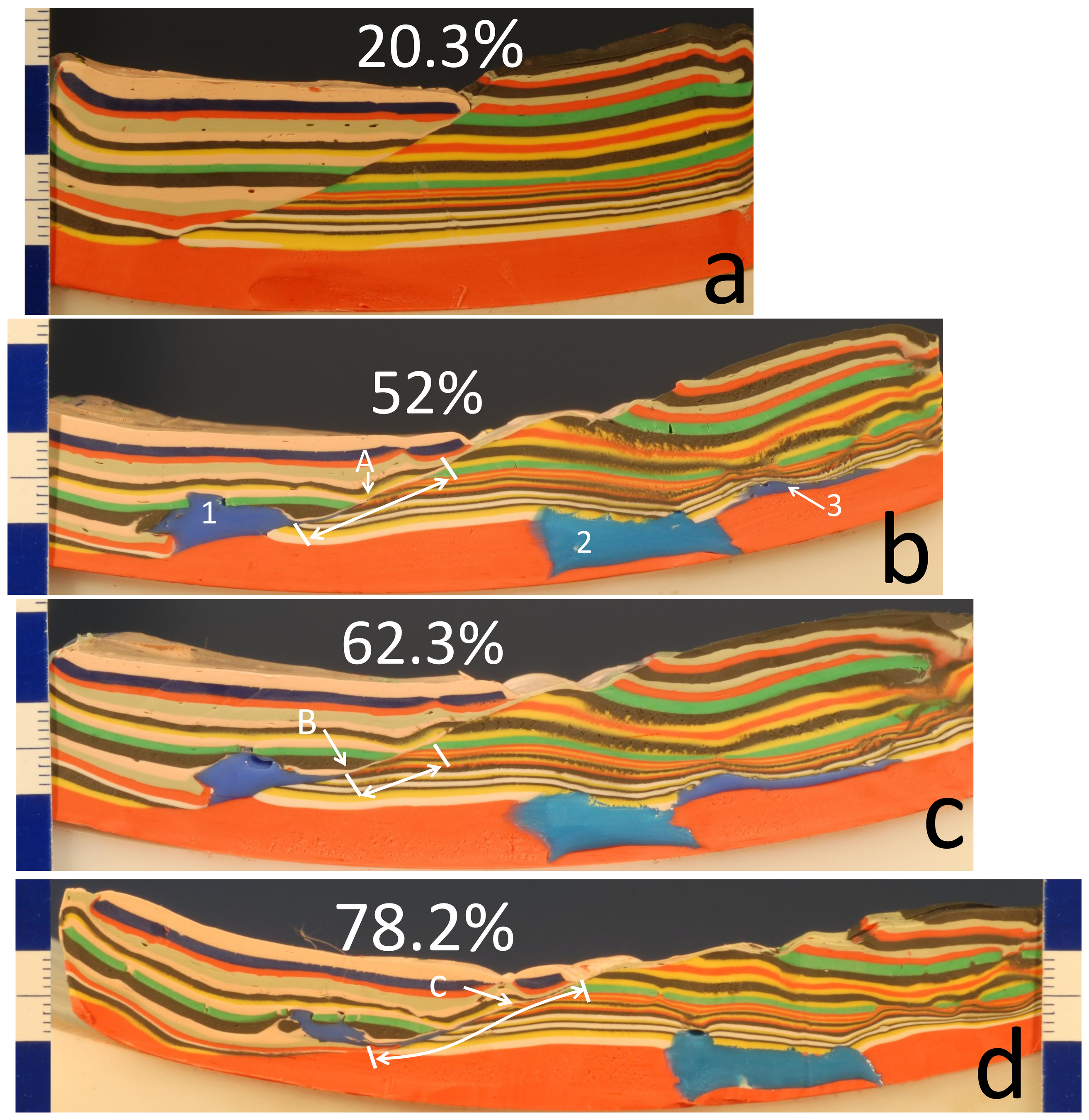
Centrifuge models were constructed using mixtures of modeling clay (Pongo© various colors and Demco™, Dow Silcone 3179 Dilatant Compound ™ and Crazy Aaron's Thinking Putty™ (silicone-based material). Mixtures of these materials were used to achieve desired viscosity and density contrasts in the models. Crazy Aaron Thinking Putty (various colors) was employed as analogs for granitic melts and were inserted as plugs into the base of the models. The mixtures used to make the models and their densities are given in Table 1. Density measurements were made using a Grabner Minidens™ densitmeter. Models were constructed so as to produce density and rheological contrasts throughout the model that simulate gneisses and granitoids. Models with and without preexisting faults were run and cohesion along pre-cut fault surfaces was reduced in certain models by the application of thin coatings of petroleum jelly. Centrifuge runs were made at 2,000rpm generating 900-1000G for durations of two to six minutes. The centrifuge operating conditions along with density contrasts and viscosities of the materials used model natural deformation durations of 10^5 -10^7 years (Ramberg (1967,1973,1981), Dixon and Summers (1985), Weijermars and Schmeling (1986)). Extension rates for the models were controlled via the collapse of a plasticene wedge at the front of the model. After each run, the model was carefully cut and photographed at the INRS laboratory facility in Quebec City.

Table 1: Materials and mixes

MIX	Density (g/cm^3)
Dow Corning silicone3179 Dilatant Compound	1.13
Crazy Aaron Blue #28	1.05
Crazy Aaron silver	1.07
Crazy Aaron emerald green	1.07
Crazy Aaron Lapis	1.05
Pongo Green	1.96
Mix 1(flesh) Pongo+Dow Corning silicone (DCS)	1.39
Mix 2 (Red)	1.48
Mix 3 (Green) Pongo +DCS	1.37
Mix 4 (Black) Demco +DCS	1.41
Mix 5 (Red 2) Demco +DCS	1.44
Mix 6 (Blue) Demco +DCS	1.26
Mix 7 (Yellow) Demco + DCS	1.54
Mix 8 (White) Pongo + DCS	1.86
Mix 9 (light Blue)	1.46
Mix 12 (Orange)	1.42

OBSERVATIONS

Figure 1

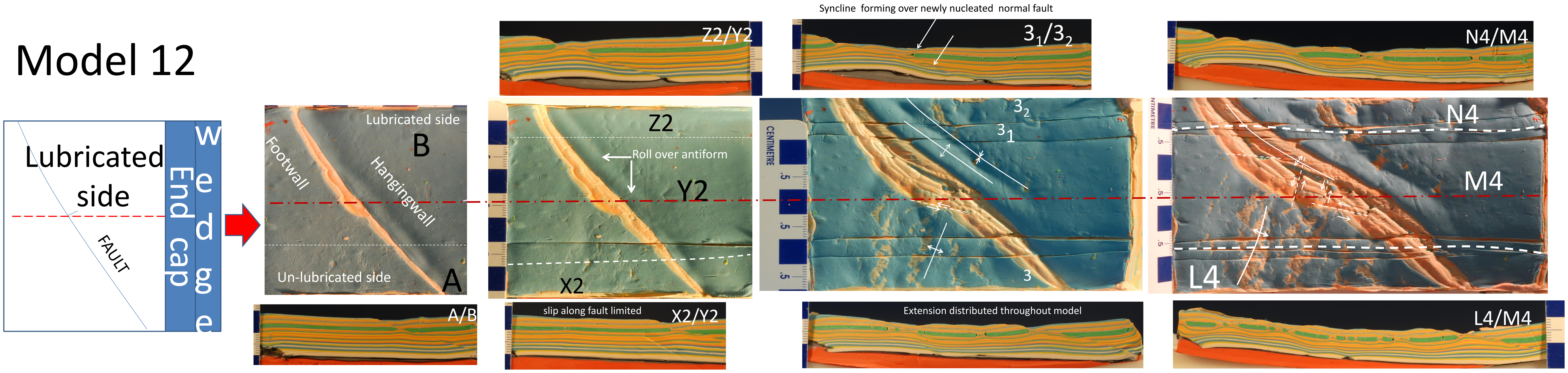


Adjacent slices of model 9 at increasing amounts of extensional strain are shown. Three analog magma bodies (Crazy Aaron Lapis (2) and Blue(1 and 3)) were incorporated as plugs into the model. The three "magma" bodies behave differently during extension. Figure 1 a: Analog magma #1 has penetrated into the shear zone (to pt A) at 52% extension. The white arrow marks the offset (from original position) along the shear (fault). Figure 1 c: At 62.3% extension. In this adjacent cut, the analog melt shows more limited penetration into the shear (point B). Note that even though this run is at a greater overall extension, offset along the shear (fault) is small relative to that observed in figure 1b. Figure 1c: In this cut, analog melt penetration extends to point C and displacement (white arrow) along the shear (fault) has increased dramatically. Analog magma bodies 2 and 3 failed to penetrate through the overlying competent layers and migrated horizontally during extension.

Figure 2

Progressive folding of a shear zone in transtension caused by differential lubrication of the shear zone.

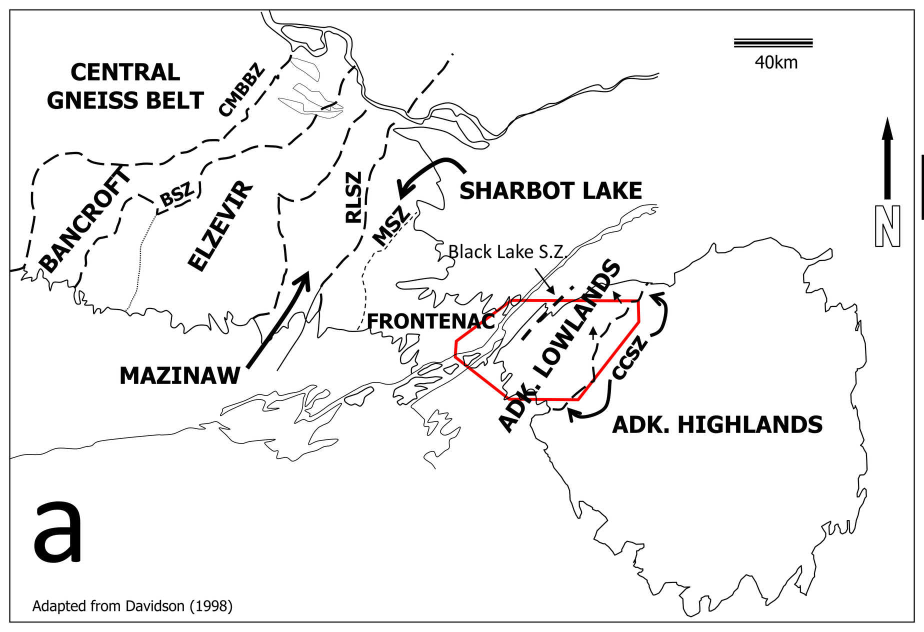
Model 12



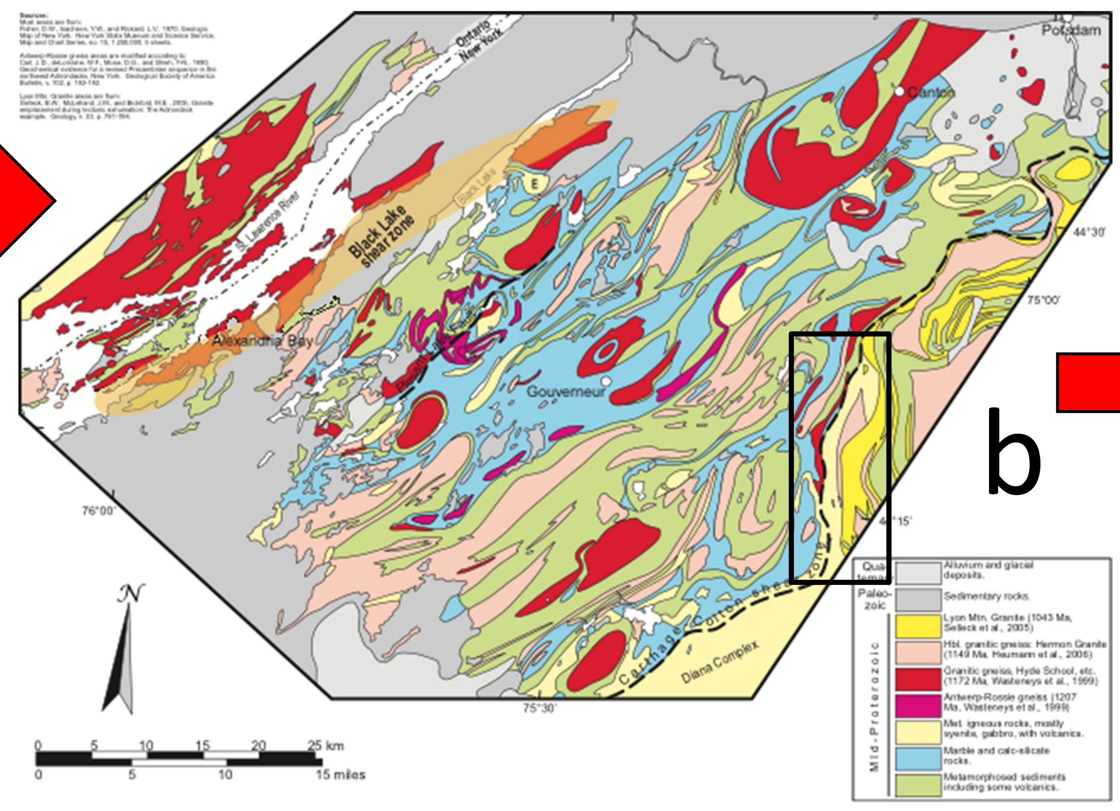
Model 12: The un-lubricated portion of the shear (bottom series of X sections) shows limited slip on the shear with the early development of boudinage throughout the model. On the lubricated (top) side, deformation is concentrated along the shear through 47% extension after which, flattening of the shear zone renders it ineffective and boudinage throughout the model accommodates much of the continued extension. Folding of the shear is initiated early (24% extension) and by 47%, compensation faults cut the shear giving the top surface a blocky appearance. Broad folding extends across the model and these folds form in response to boundinage of competent layers (green Pongo) in the model. The red dashed line marks the lubricated non-lubricated boundary.

DISCUSSION and CONCLUSIONS

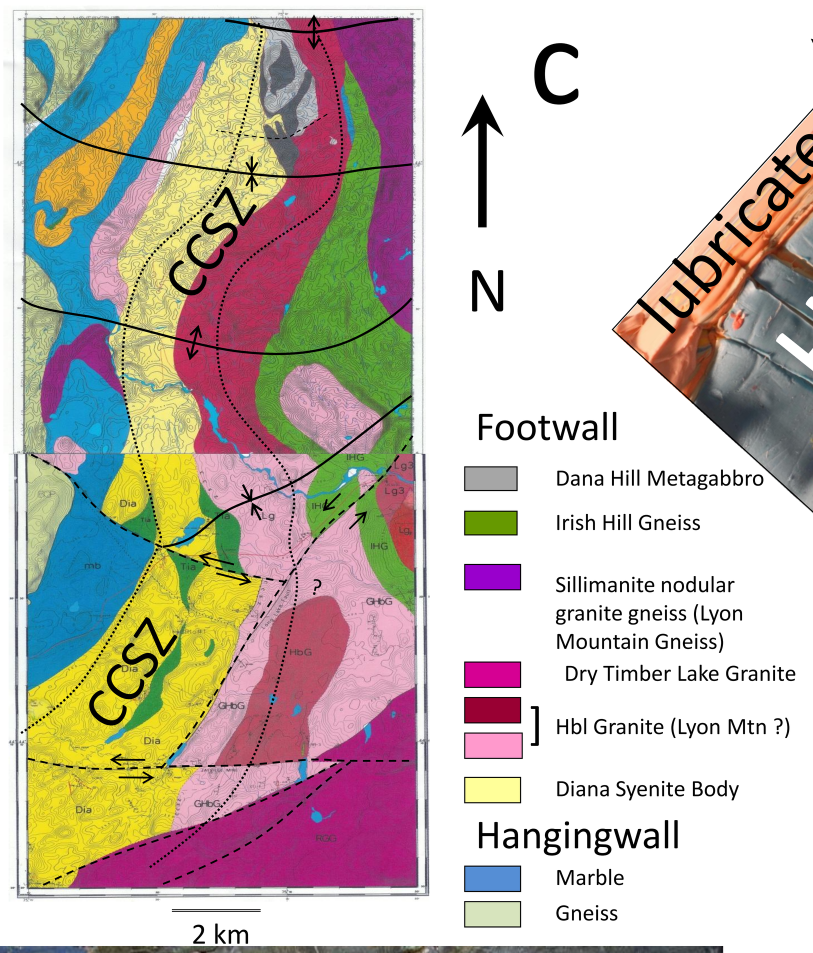
Grenville Province (NY/Ontario)



Adirondack Lowlands



CCSZ Carthage Colton Shear Zone



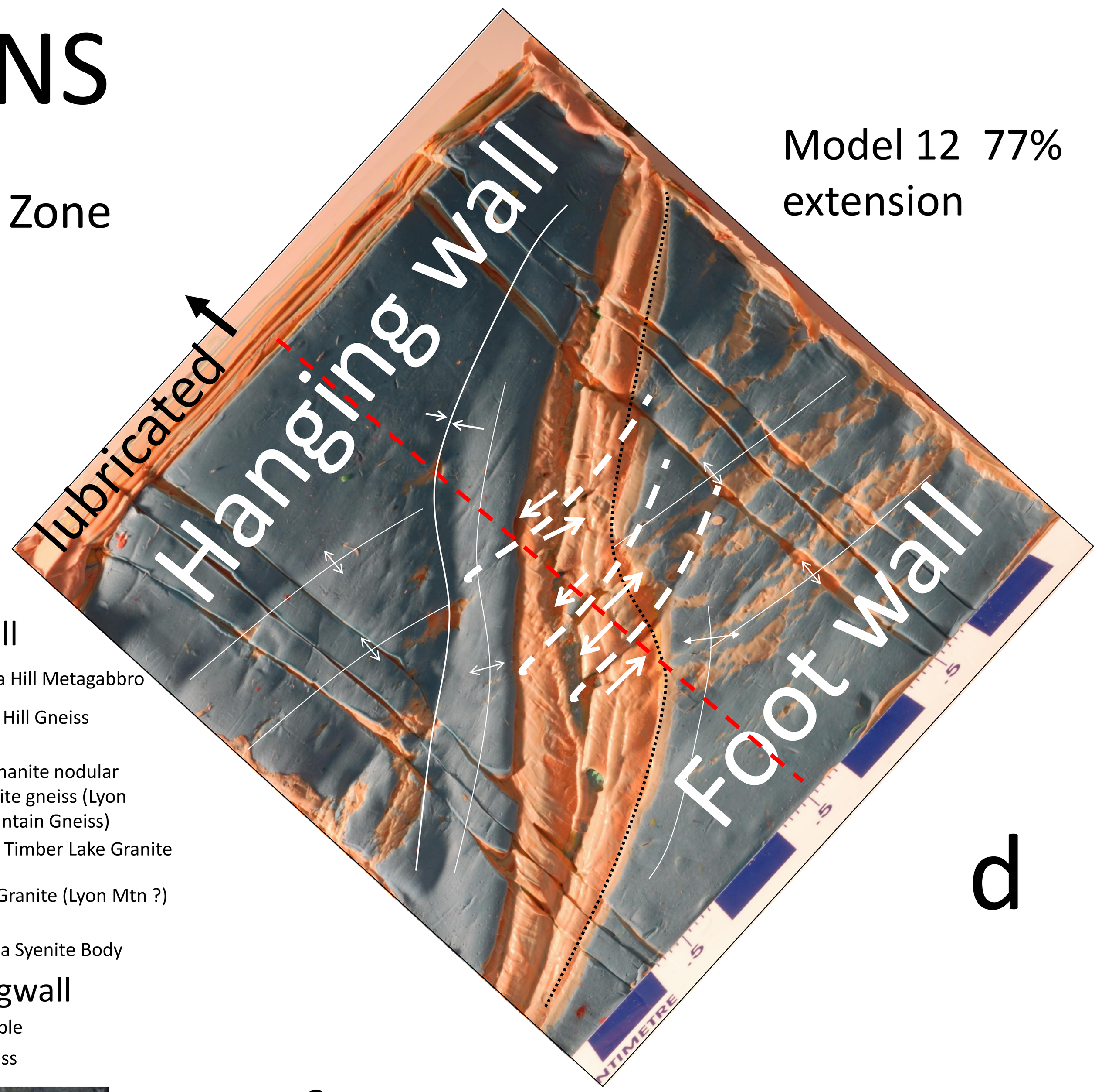


Figure 3 a-d

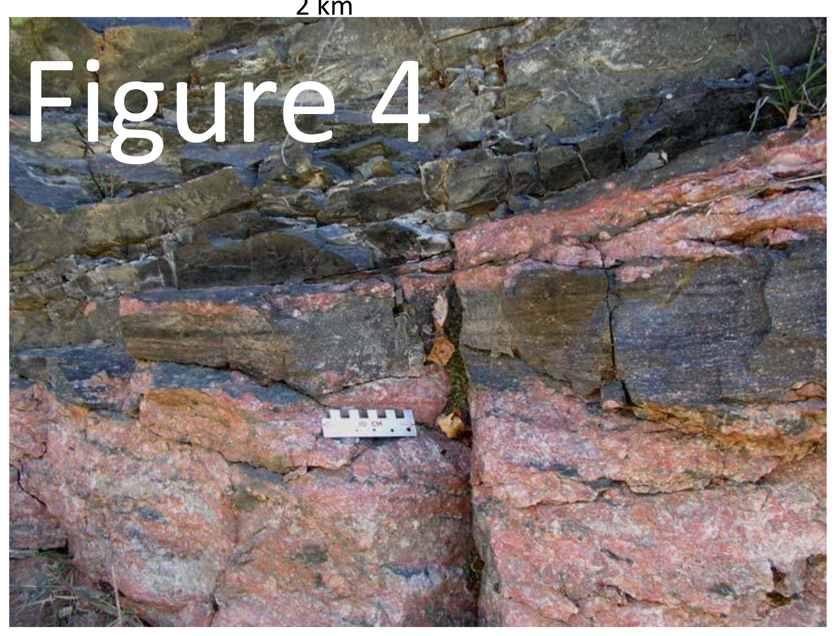
Comparisons with the Carthage-Colton Shear Zone

CCSZ is a major transtesnional detachment that separates the Adirondack Lowlands (hangingwall) and Highlands (footwall) terranes (fig. 3a,b). This shear operated through the late Ottawan Orogeny (1060-950 Ma) facilitating late top to the NW collapse of the Lowlands (Streepey et al. 2004). The shear zone is folded on regional and outcrop scales (fig 31-c). Folding of the detachment was syn-tectonic (Johnson et al. 2004) and top to the NW normal sense shear zone stretching lineations parallel fold hinge orientations.

Movement along the shear was coeval (see fig. 4) with intrusion of 1042 Ma Lyon Mountain magmas which cut and intrude the shear zone and are deformed by it (see fig. 4)(Selleck et al. 2005). Distribution of Lyon Mountain Granite is heterogeneous along the footwall (see figure 3b) and may have acted to locally lubricate portions of the shear zone causing folding and the development of compensation faults and shear zones (Fig. 3c).

The resulting geometry of the CCSZ is similar to what is observed in the analog models that incorporate magmatic injection and along-strike variation in lubrication of a detachment during transtension (compare figs. 3c and d)

Figure 4



1042 +/-7Ma pegmatite intruding into mylonitic calc-silicate gneiss with in the Carthage-Colton Shear Zone (Selleck et al. 2005). Pegmatite bodies cross cut mylonitic CCSZ fabric and are in places strongly deformed. Location: Brouses Corners, Clair, NY Photo: B. Selleck.

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