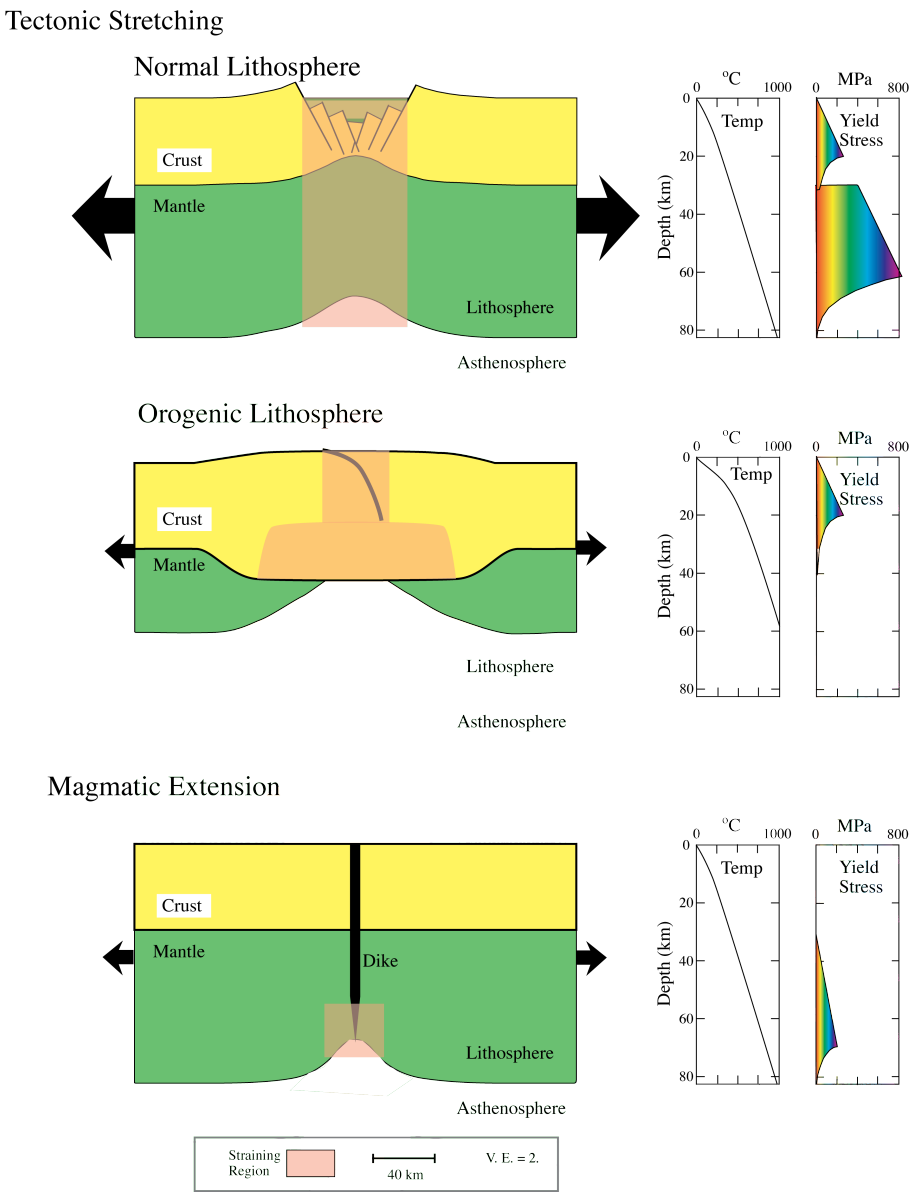
How plate boundaries extend at moderate force levels?

1. Lower friction
2. Thicken crust
3. Add Magma

In Talk

A. Constraints on friction

B. Magma distribution



What top geodynamic controversy of the 1950's was stimulated by data from Alberta?

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Hint: It has to do with fault friction

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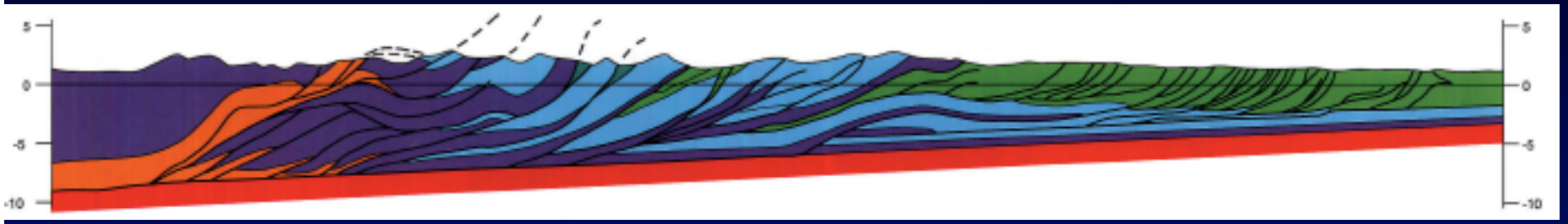
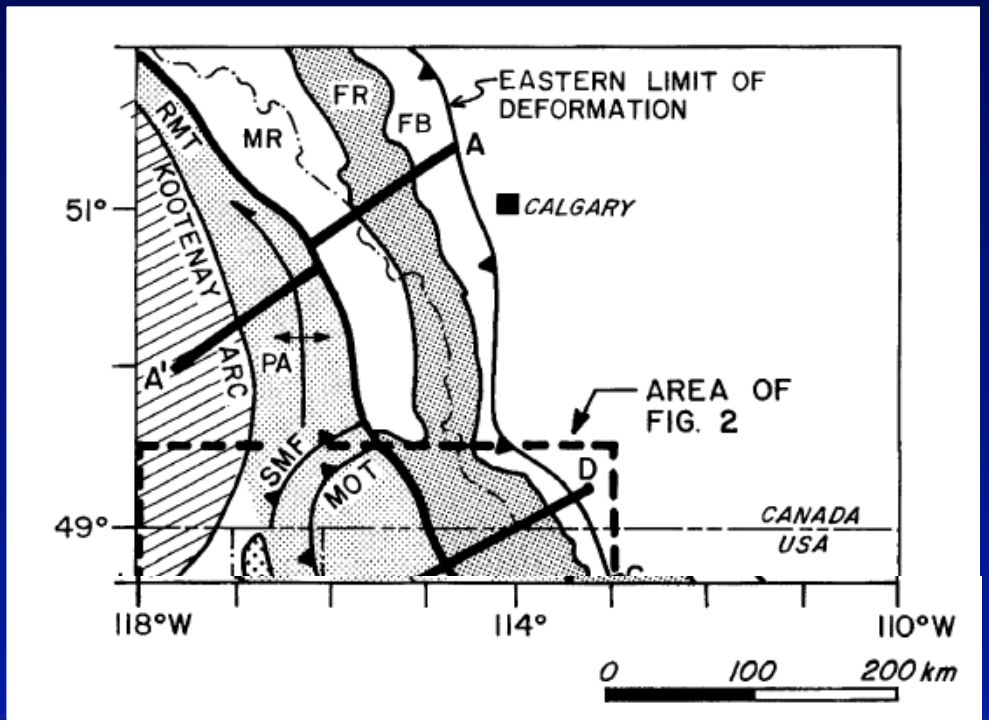


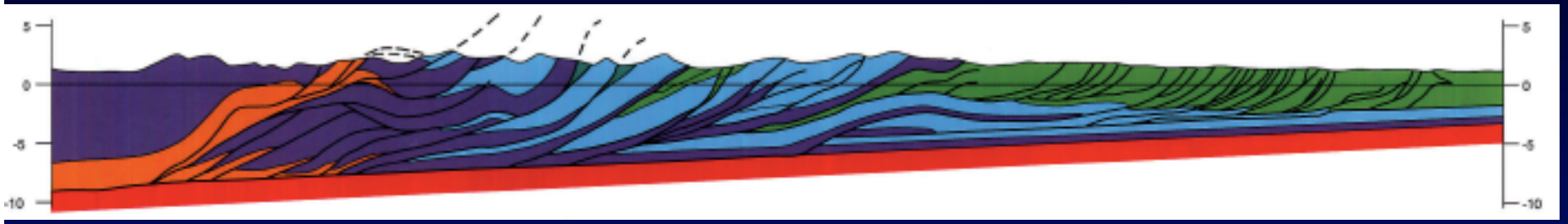


After Price (1981)

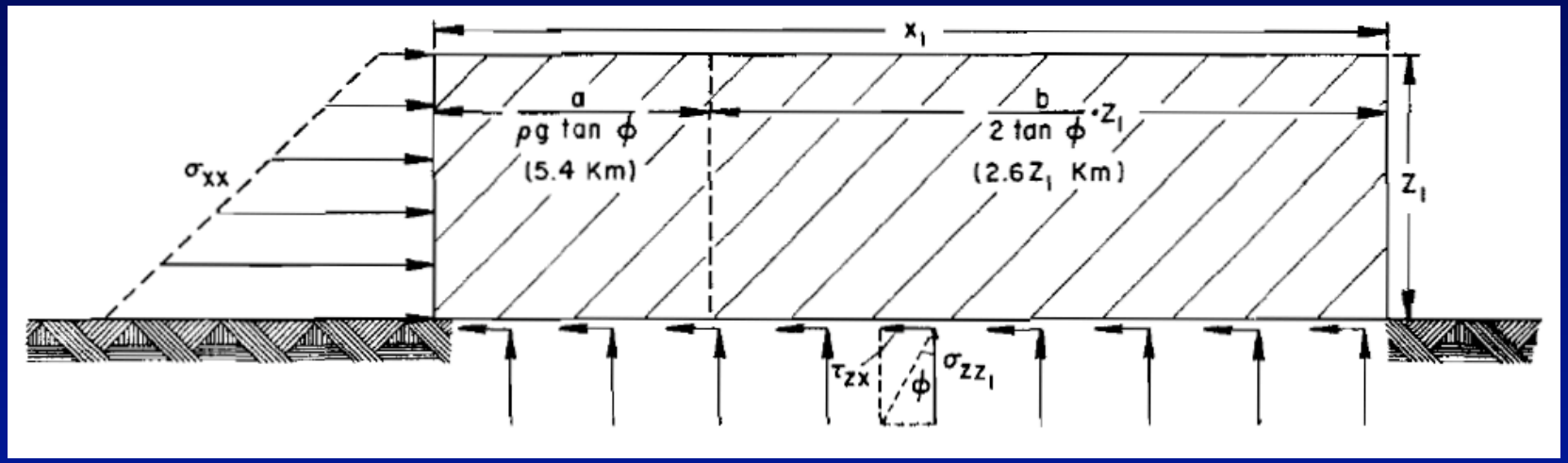
Low-angle thrusting

What top geodynamic controversy of the 1950's was stimulated by data from Alberta?

Hint: It has to do with fault friction



After Price (1981)

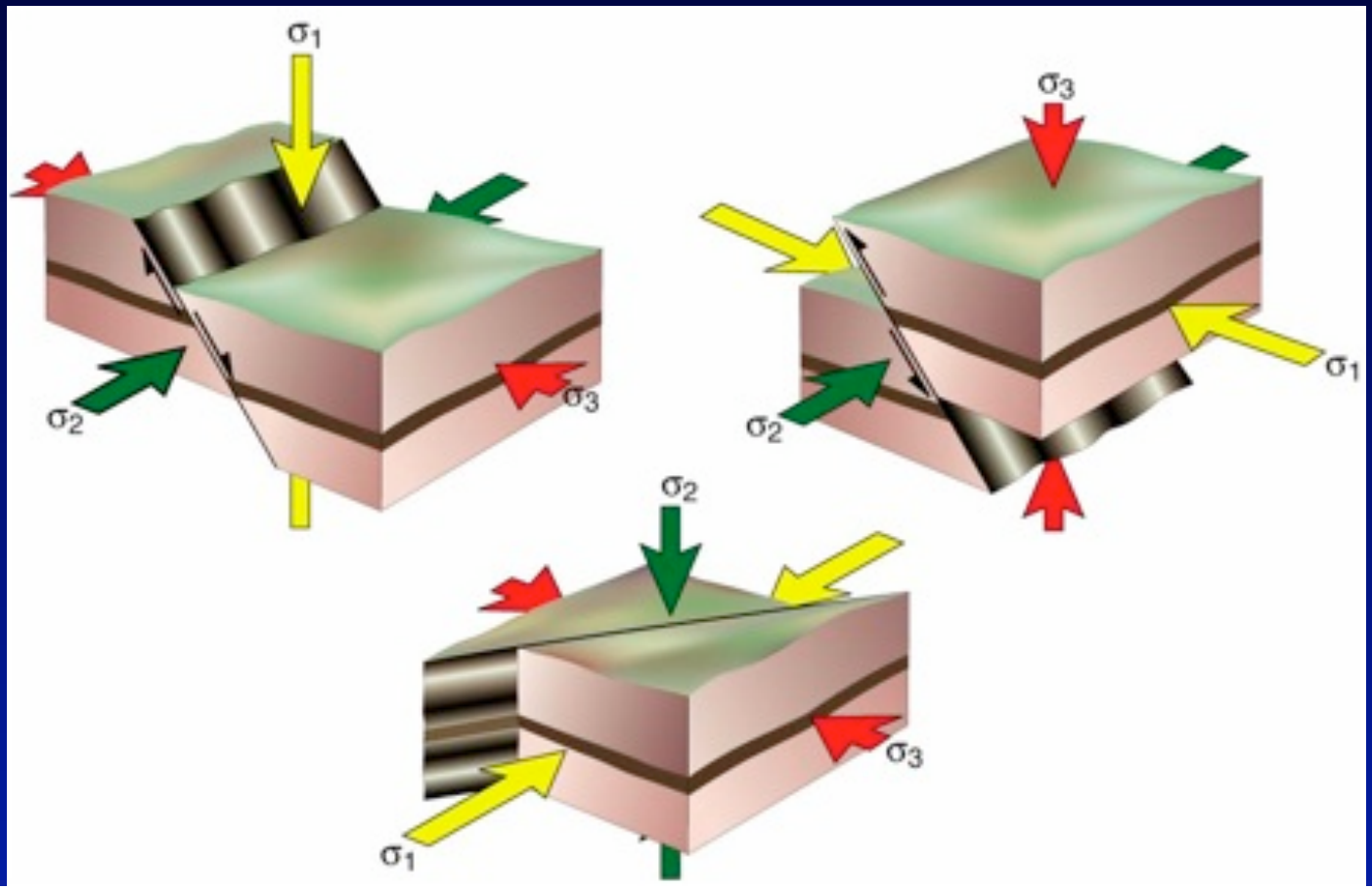


King and Hubbert (1959)

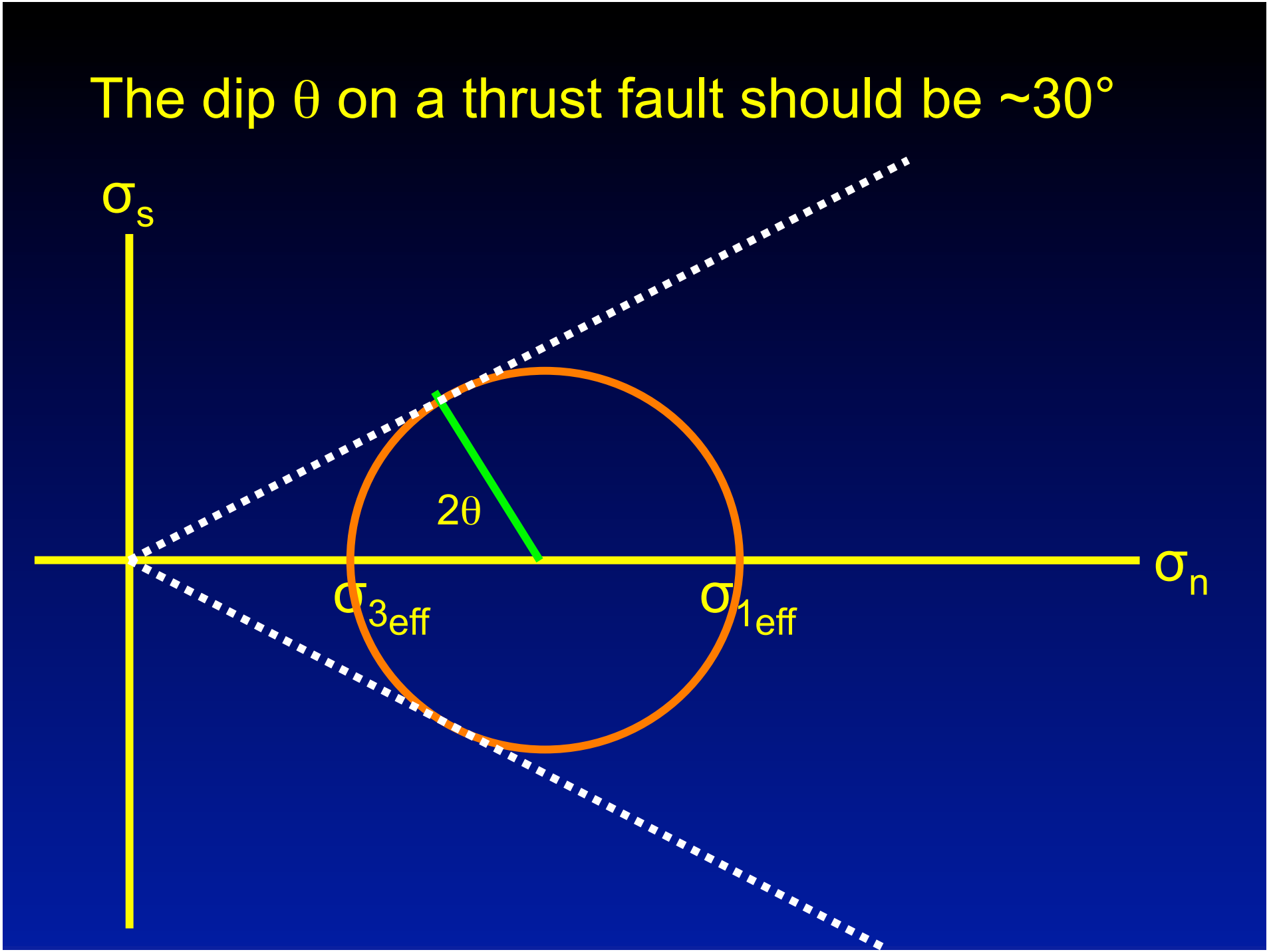
High pore pressure allows low-stress slip on low-angle thrusts

Anderson's theory of faulting

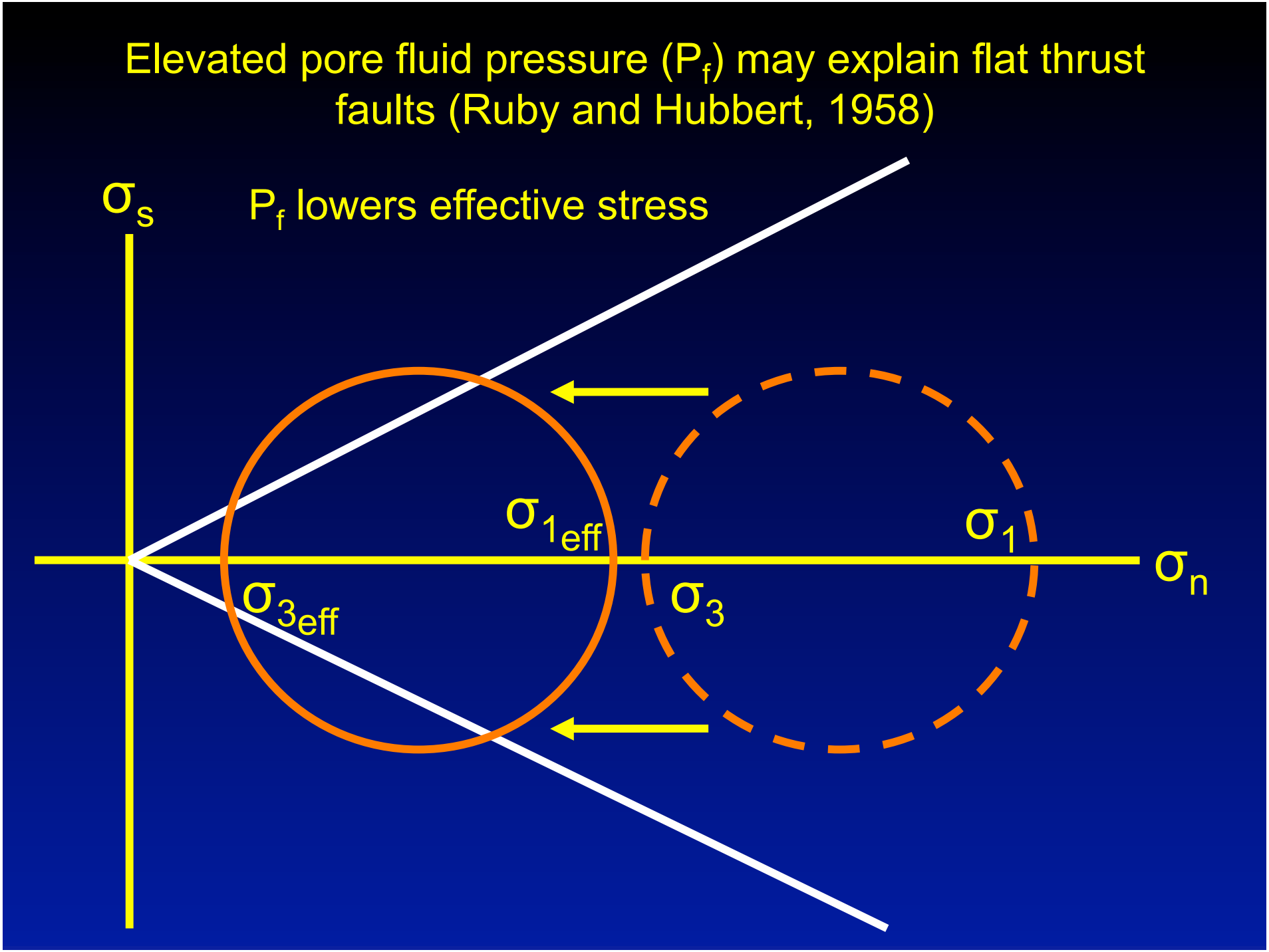
- Reverse faults: should form at ~30° dip
- Normal faults: should form at ~60° dip
- Strike-slip faults: should form at ~90° dip



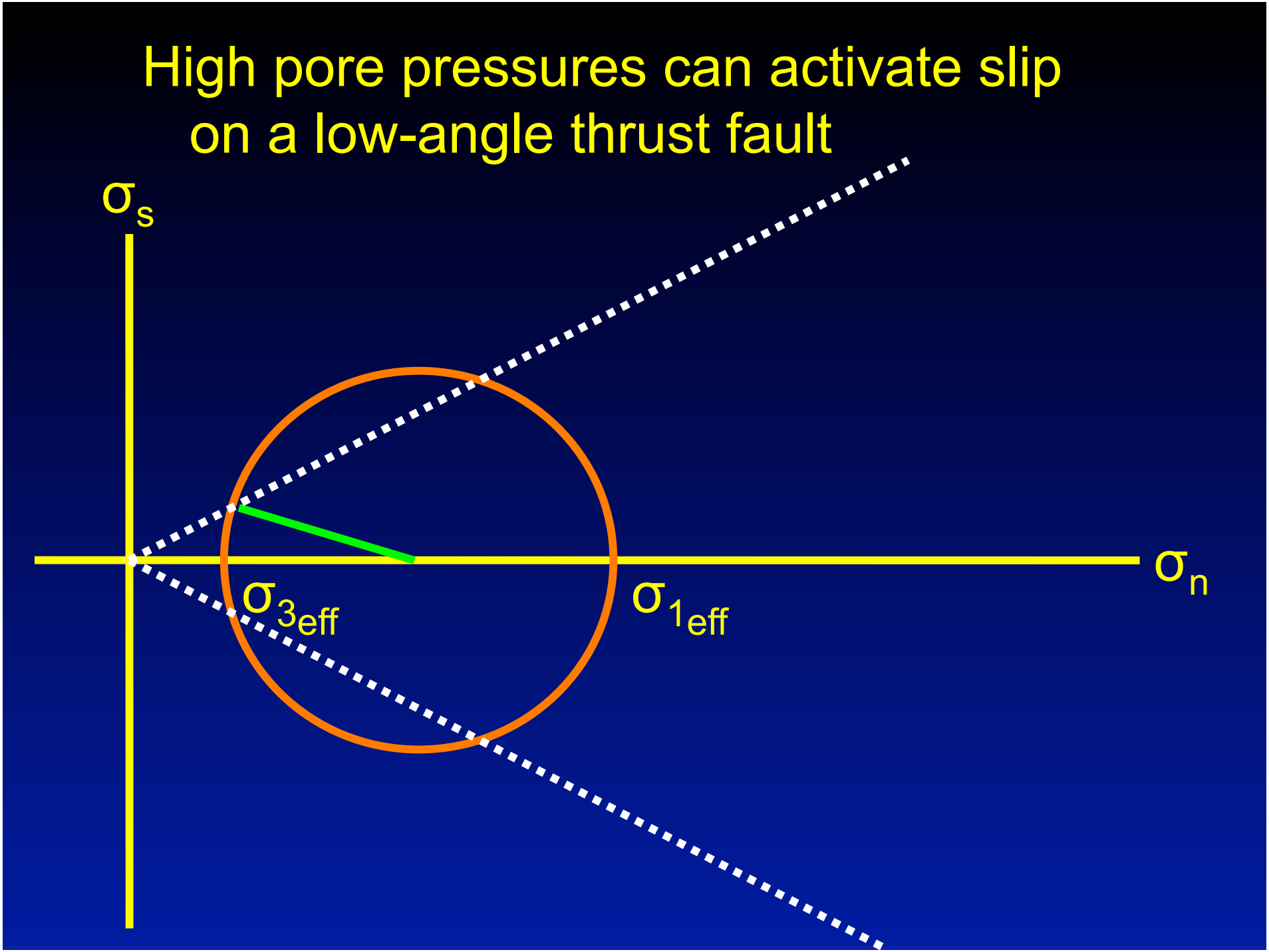
The dip θ on a thrust fault should be ~30°



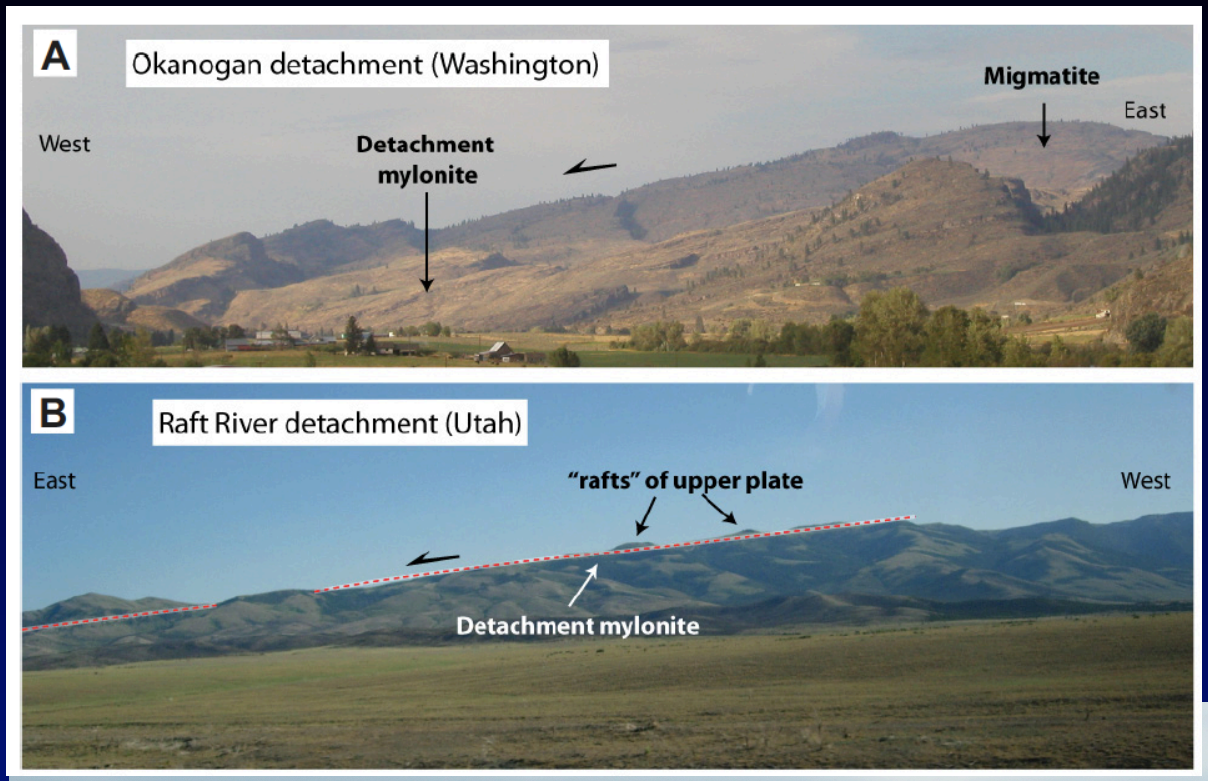
Elevated pore fluid pressure (P_f) may explain flat thrust faults (Ruby and Hubbert, 1958)



High pore pressures can activate slip on a low-angle thrust fault



The problem is worse for ‘low-angle normal faults’ : pore pressure does not work



Core Complexes involve ‘low-angle’ normal faults

A&B
Whitney et al., 2013

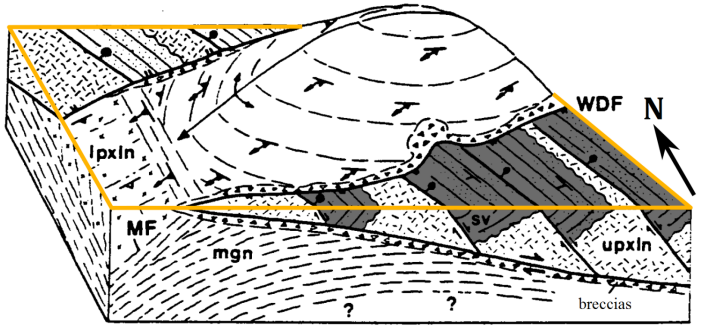
Fergurson Island, D’Entrecasteaux Islands, Papua, New Guinea
The youngest metamorphic core complexes

Buck, 2010
unpublished

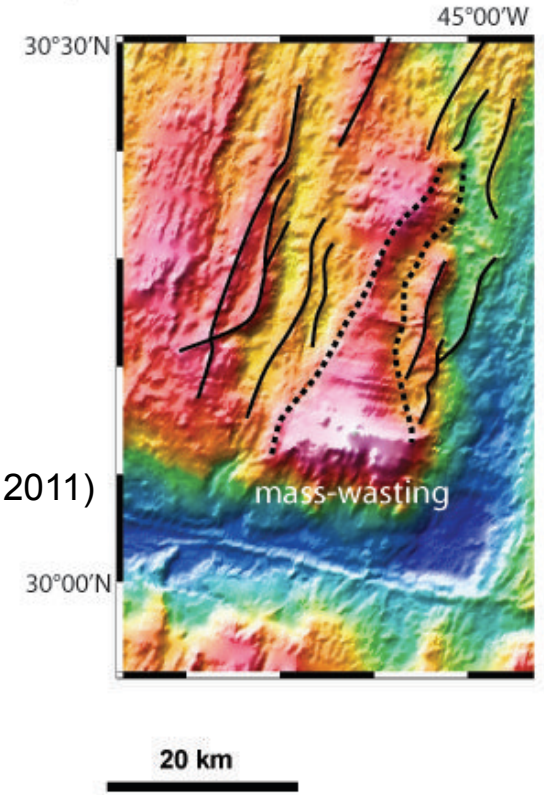
Constraints on the Strength of Faults from the Formation of Rider Blocks in Continental and Oceanic Core complexes

W. Roger Buck,
Lamont-Doherty Earth Observatory of Columbia University, New York
Eunseo Choi,
University of Tennessee, Memphis
Luc Lavier,
University of Texas, Austin
Kenni Petersen,
Aarhus University, Denmark

Problem: What do fault-bounded rider blocks, seen on the lower plate of core complexes, imply about fault strength?



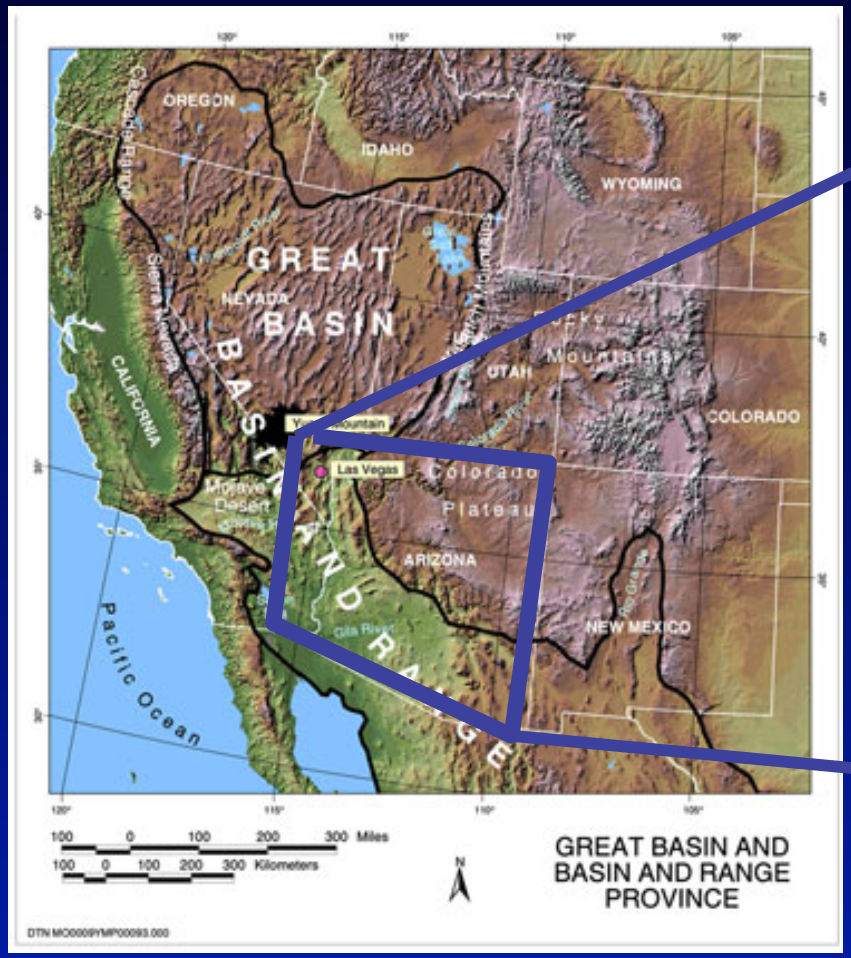
Whipple Mountains Metamorphic Core Complex (Davis, 1980)

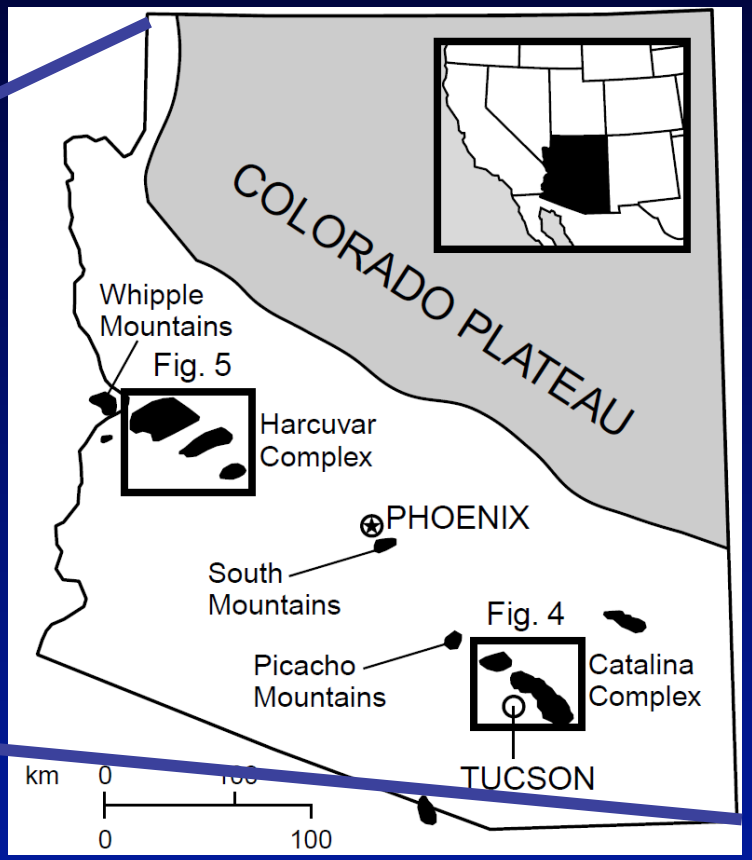


Atlantic Massif Oceanic Core Complex (Reston and Ranero,2011)

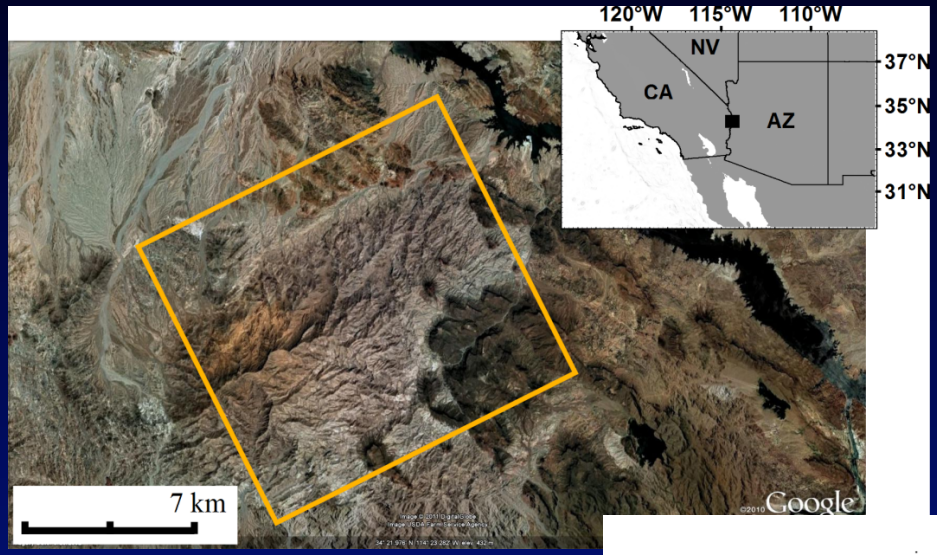
What is a core complex?

The most recently identified major tectonic feature (e.g. Coney, 1980, with high grade metamorphic 'cores' exhumed by extension concentrated on a single detachment fault.



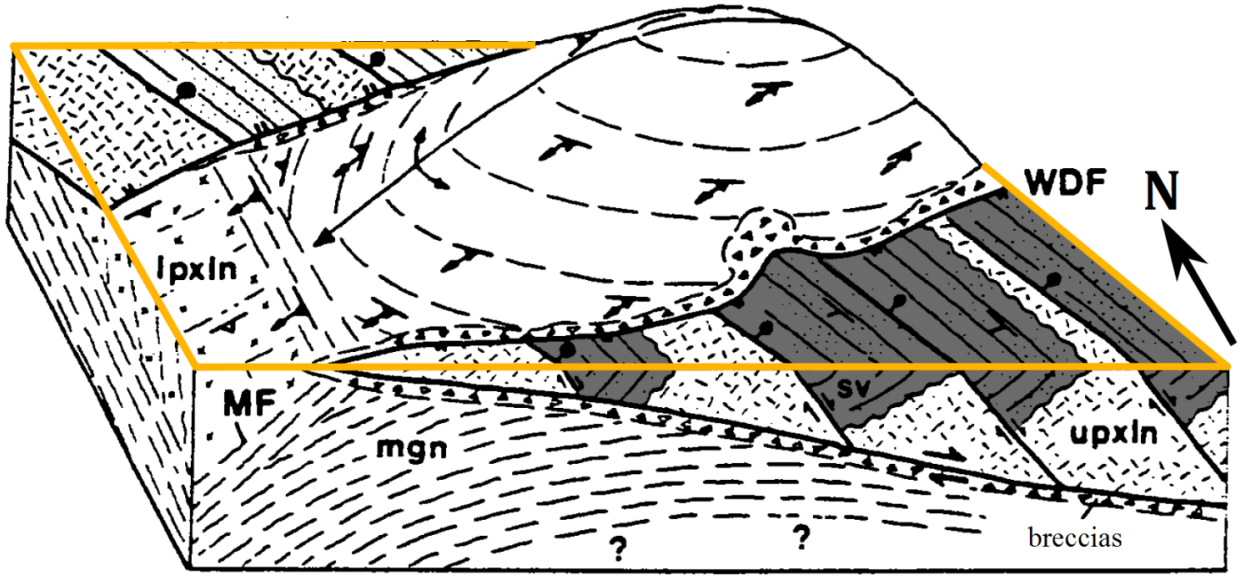


Core Complexes: Domed detachment surfaces dipping at low-angles, or overturned, often with overlying 'rider blocks'

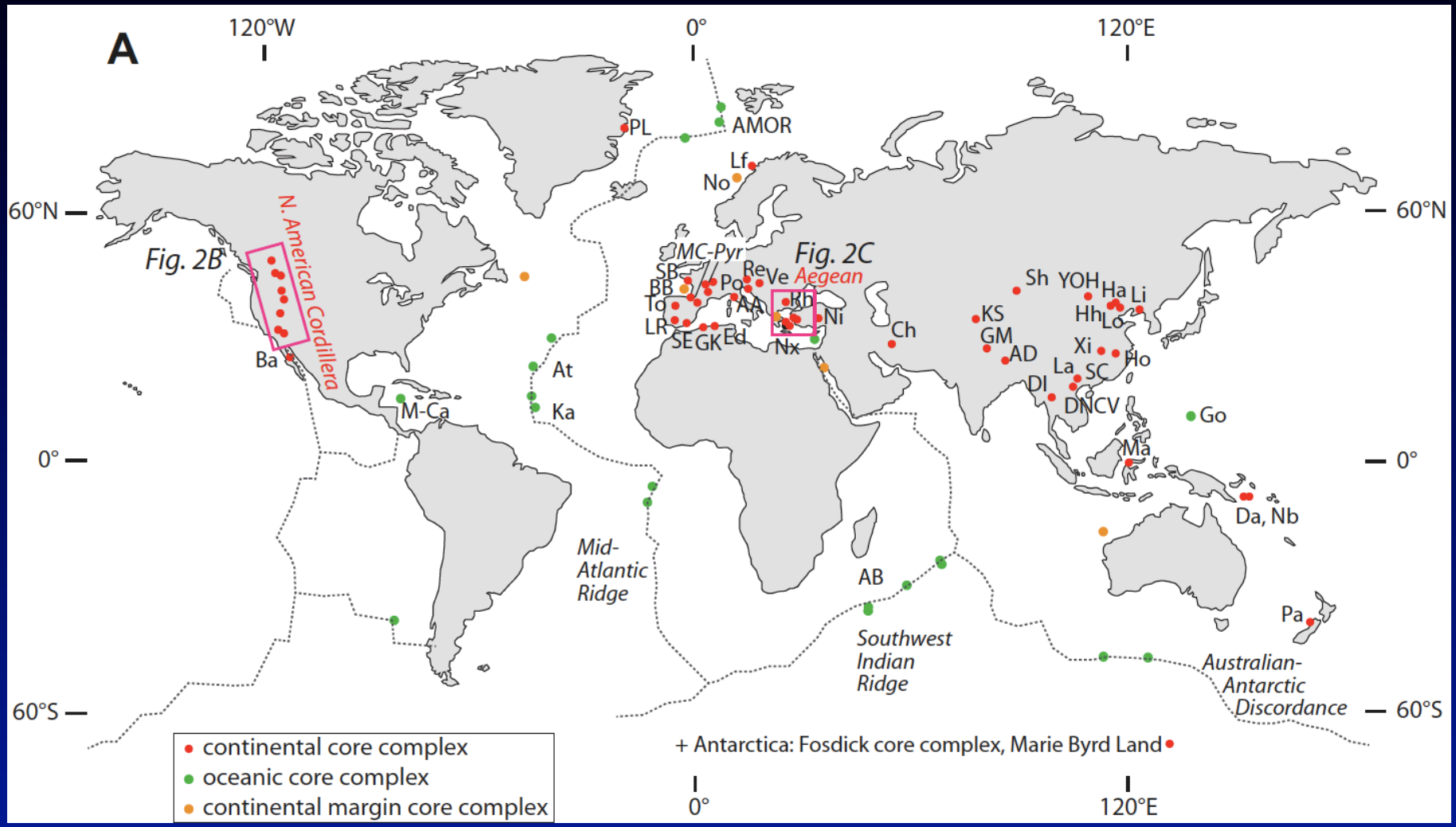


The Whipple Mountains

Davis, *Geol. Rundsch.*, 1988

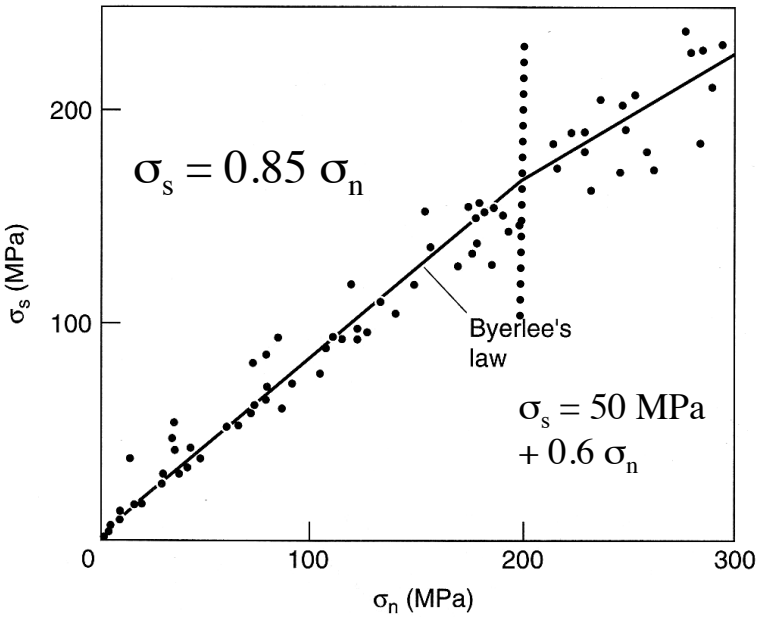


Where are Core Complexes Found?



Whitney, Teyssier, Rey, Buck (GSA Bulletin, 2013)

How to get low-angle faults
1. Super weak faults

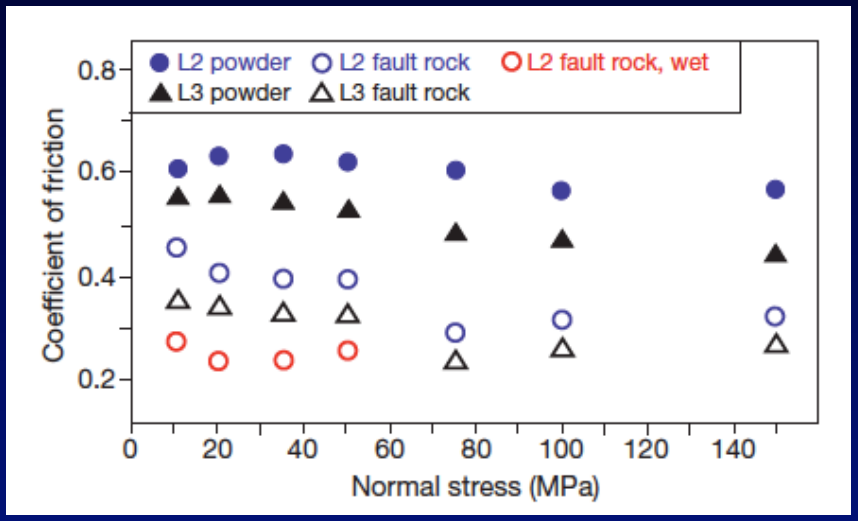


Experimental data show that failure criterion for frictional sliding is largely independent of rock type (Byerlee, 1978)

Fault zone fabric and fault weakness

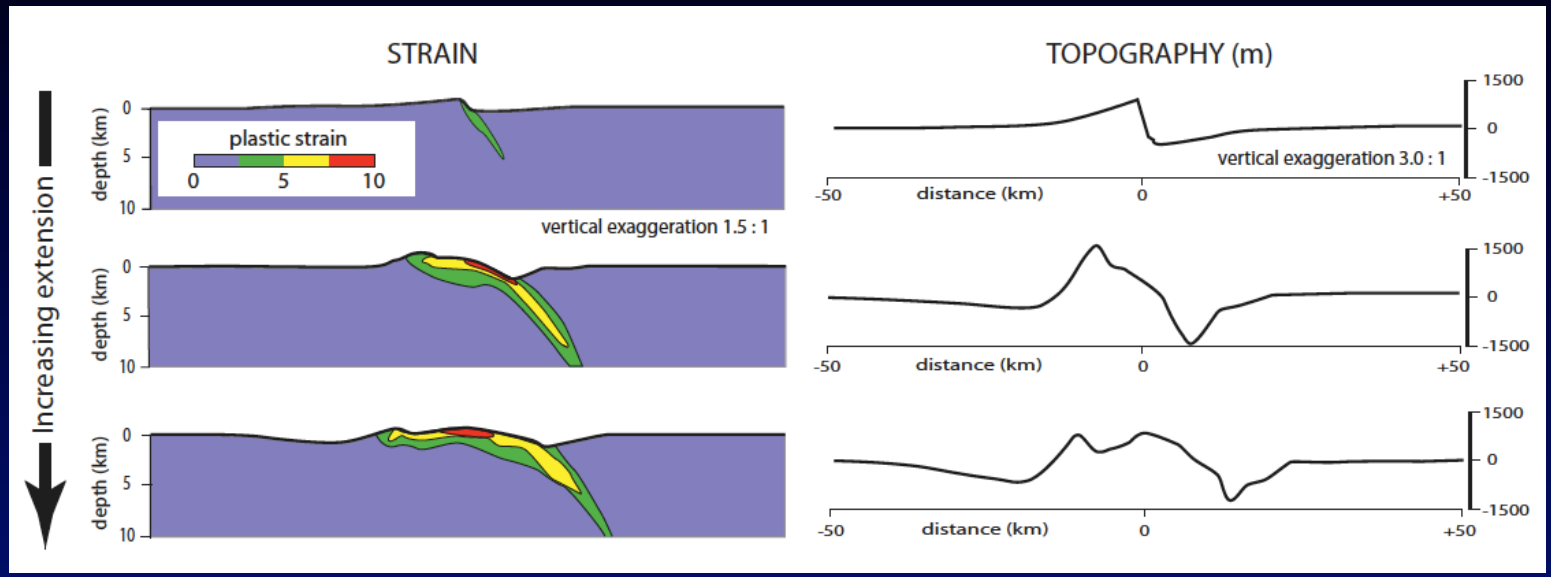
Cristiano Collettini[1], André Niemeijer[2]†, Cecilia Viti[3] & Chris Marone[2]

NATURE | Vol 462 | 17 December 2009



Can happen with weak material in the fault zone, But, weak material is not found everywhere

How to get low-angle faults?
2. Rotation of exhumed fault



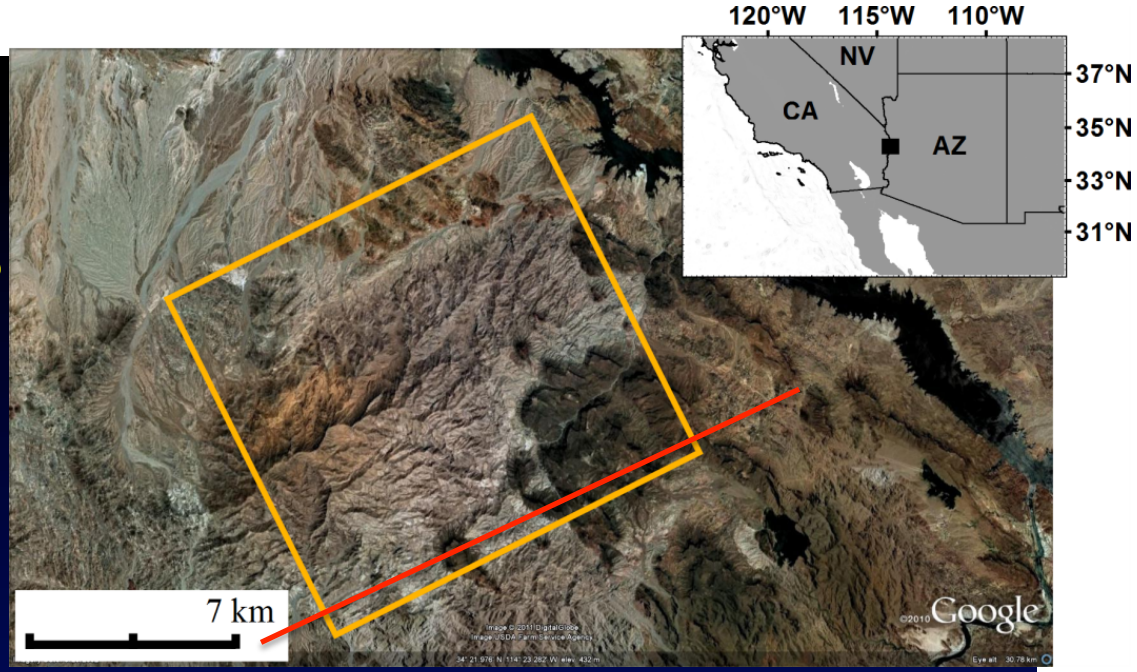
Lavier, Buck and Poliakov, JGR, 2000

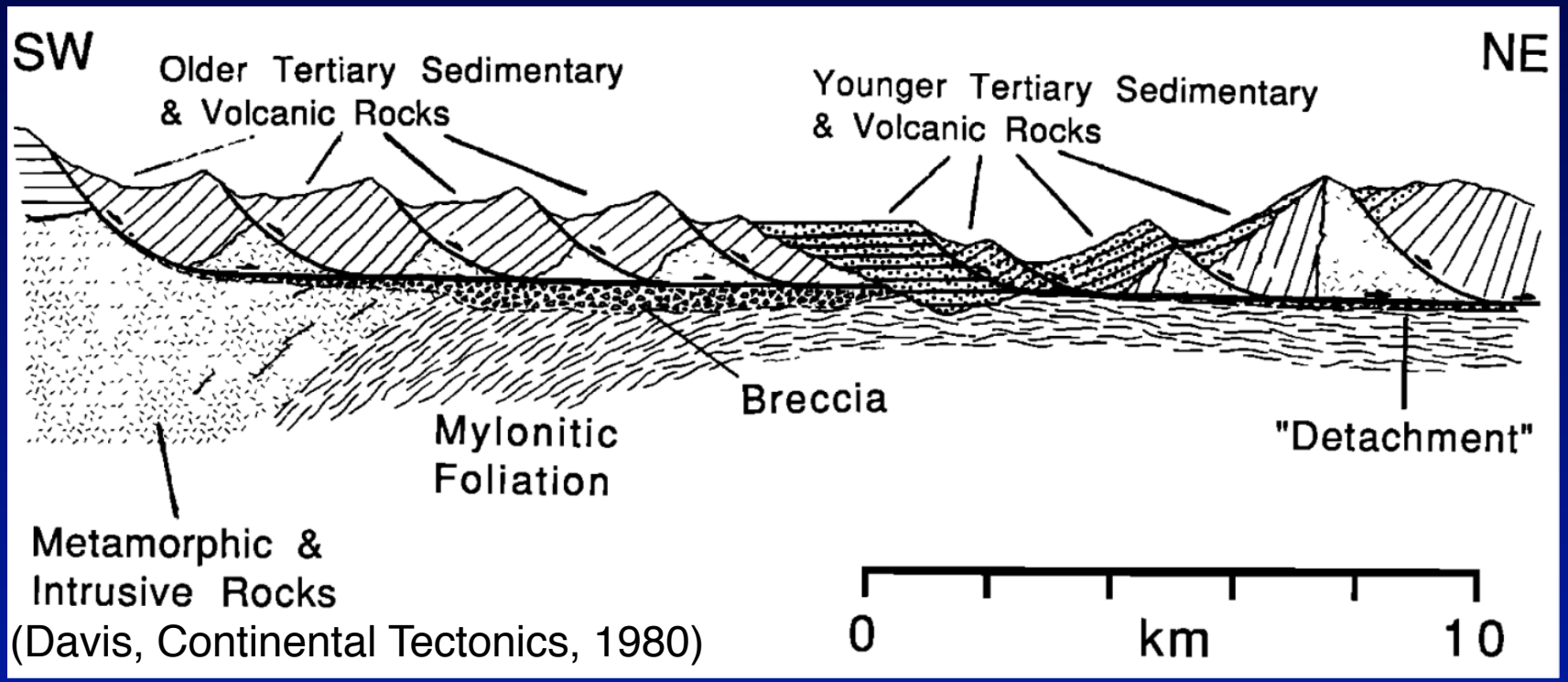
Paleomagnetic data from drill samples in Oceanic Core Complexes shows > 50° rotations

Models give large offsets rotations when faults are weaker than a given amount, depending on brittle layer thickness

What is a rider block?

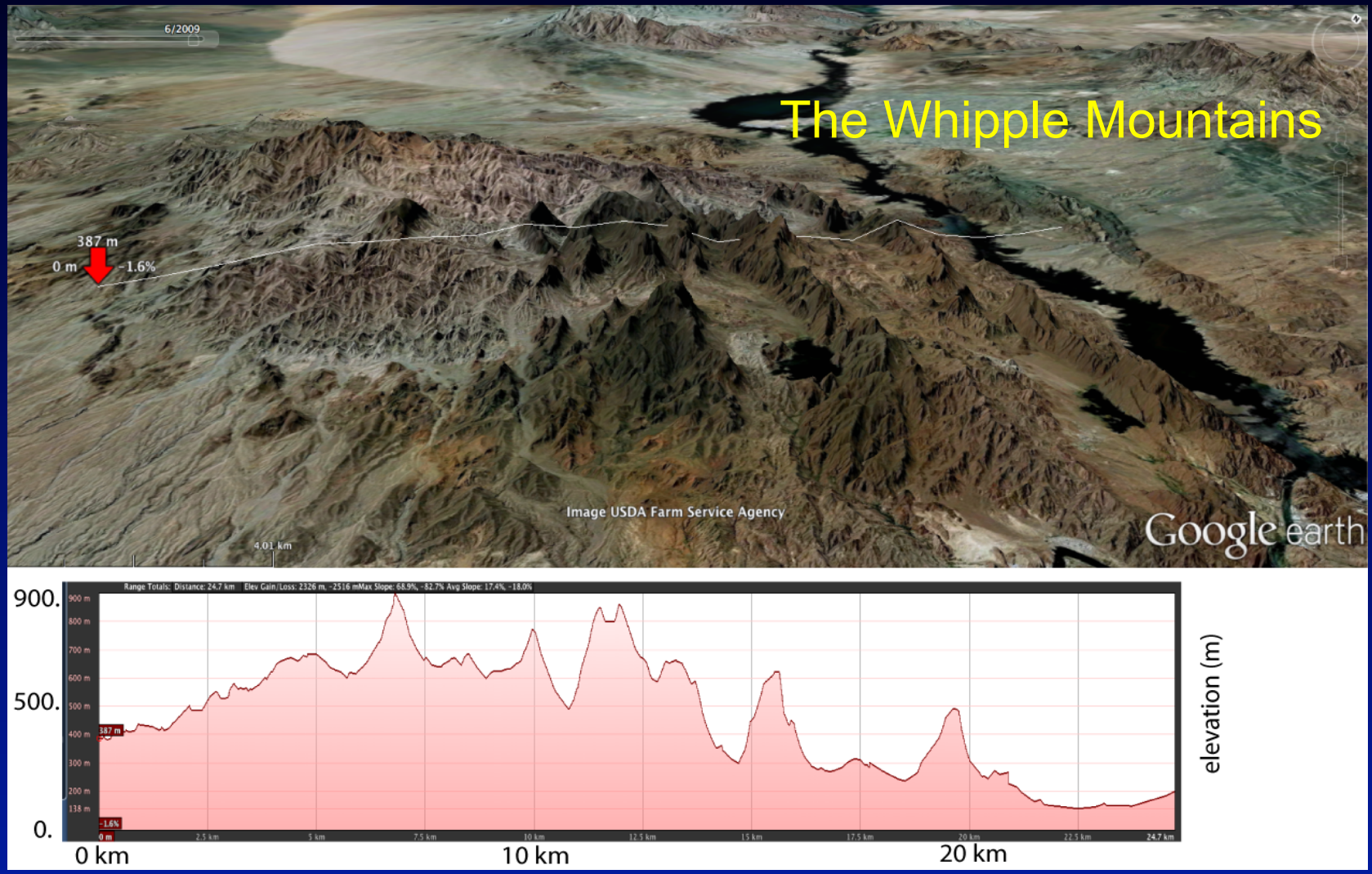
Fault bounded, rotated, syn-extensional, volcano-clastic blocks (aka rafted blocks)

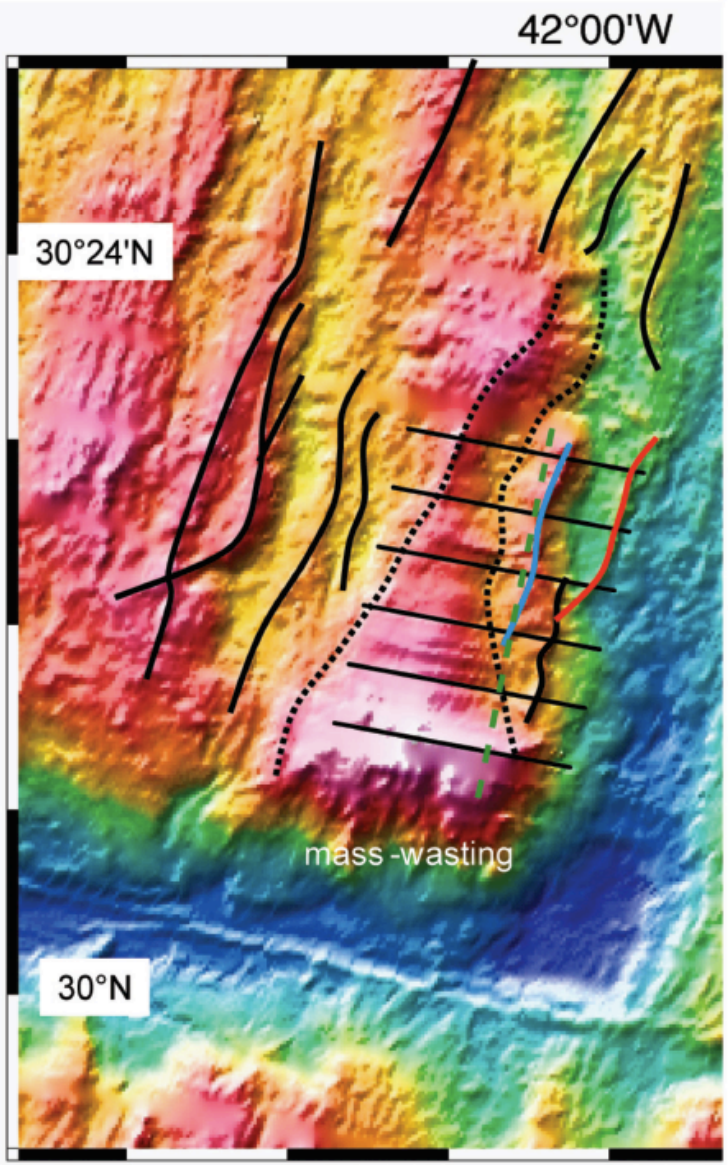


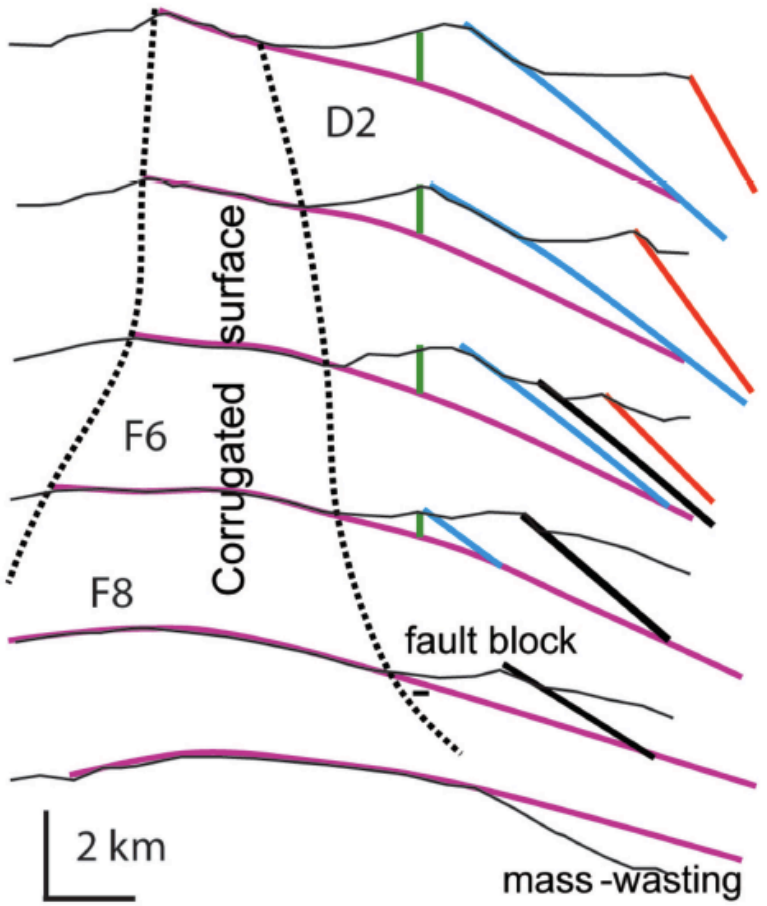


(Davis, Continental Tectonics, 1980)

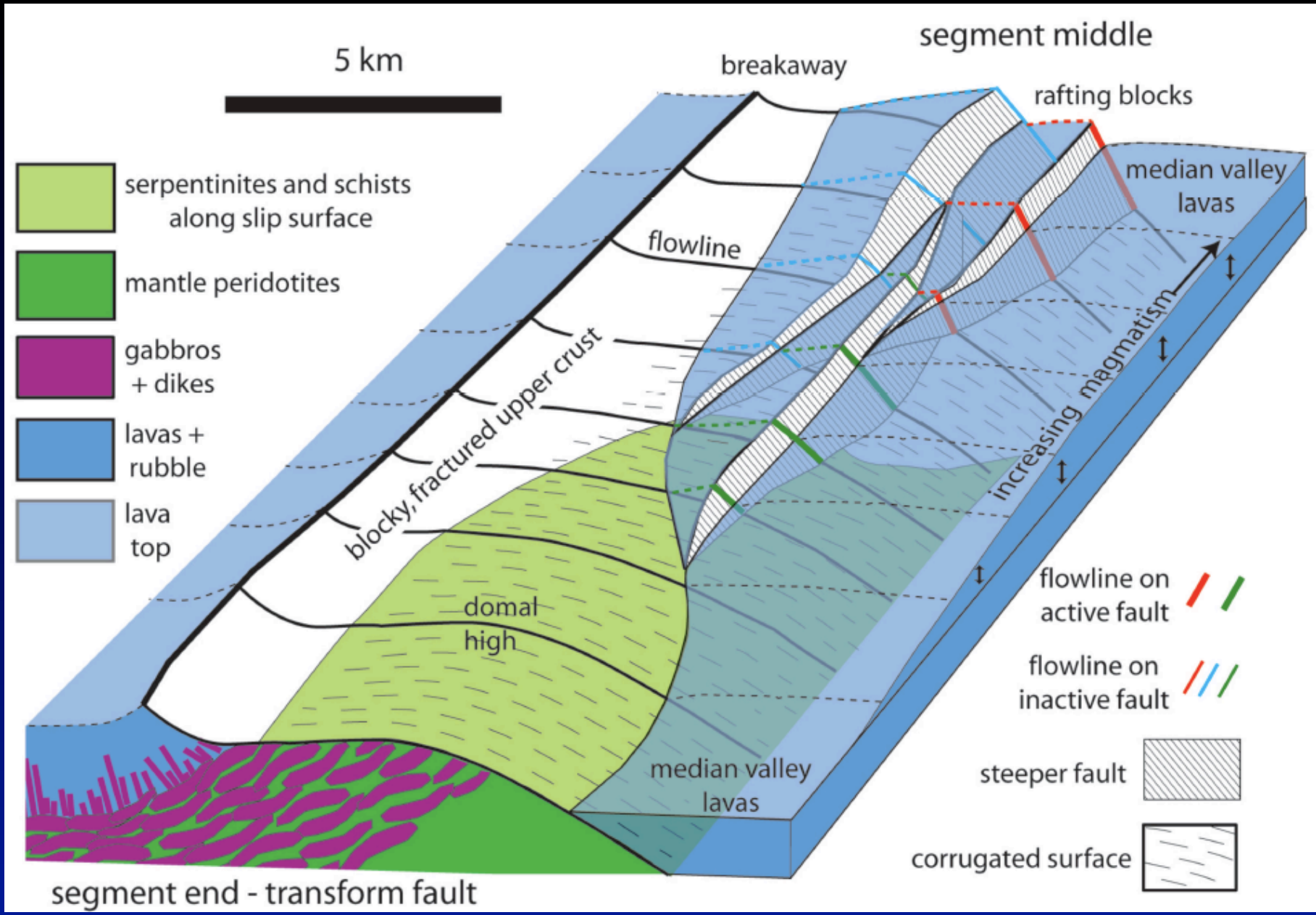
Core Complexes: Domed detachment surfaces dipping at low-angles, or overturned, often with overlying 'rider blocks'





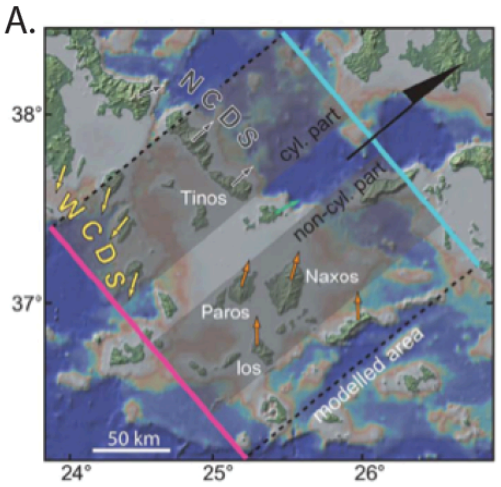


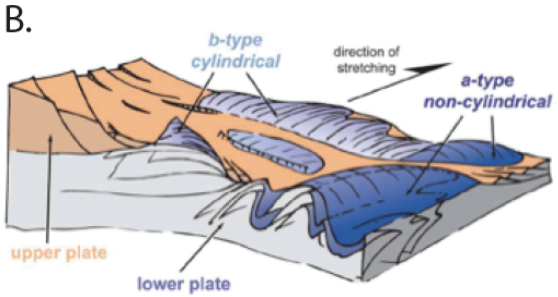
Atlantis Massif (from Reston and Ranero, 2011)

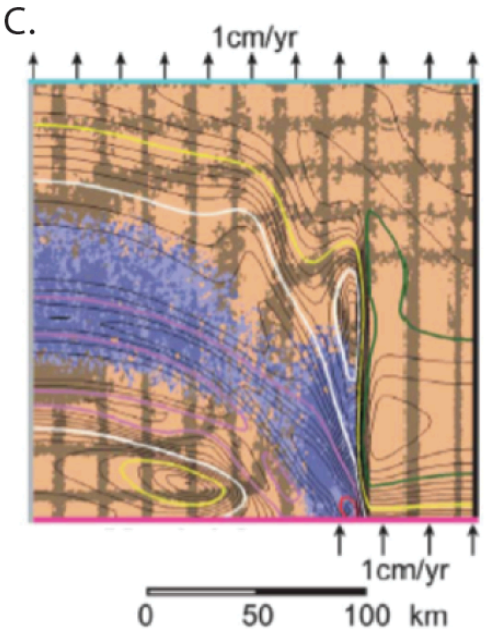


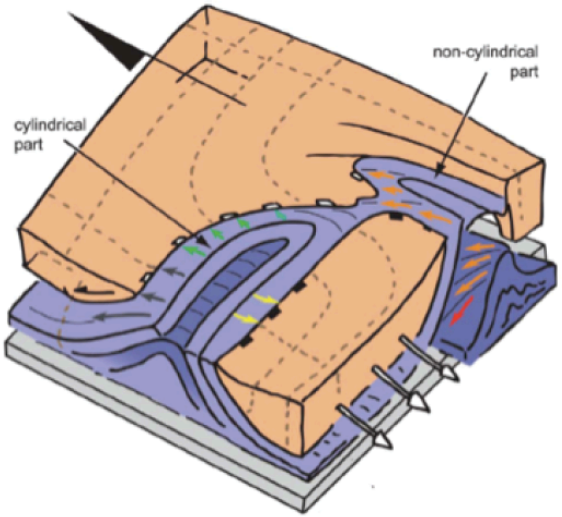
Interpretation of Reston and Ranero (2011)

Models of Core Complex Domes: Le Pourhiet et al. (2012)





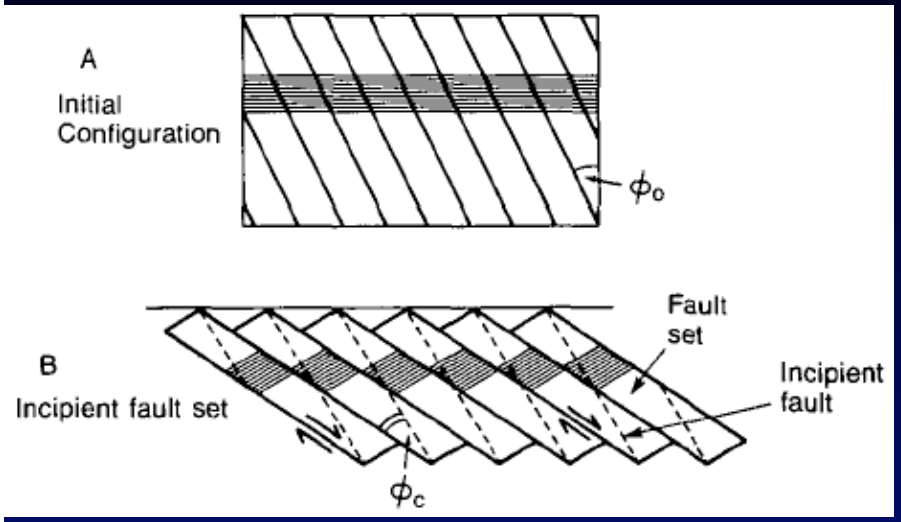




Fault mechanics and the kinematics of block rotations

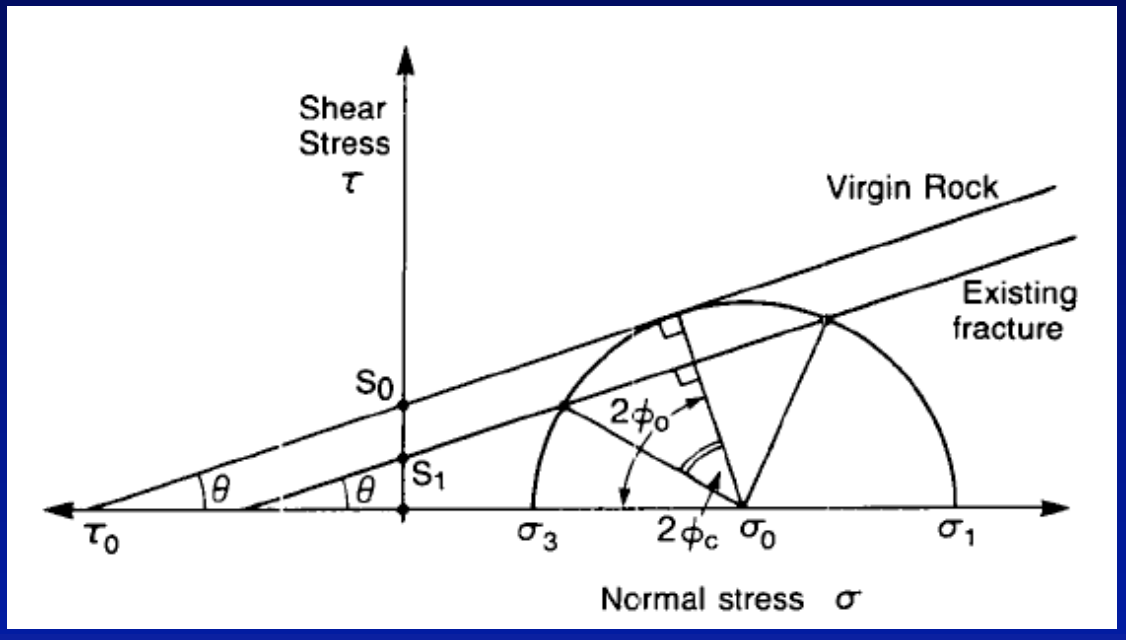
Amos Nur
Hagai Ron
Oona Scotti

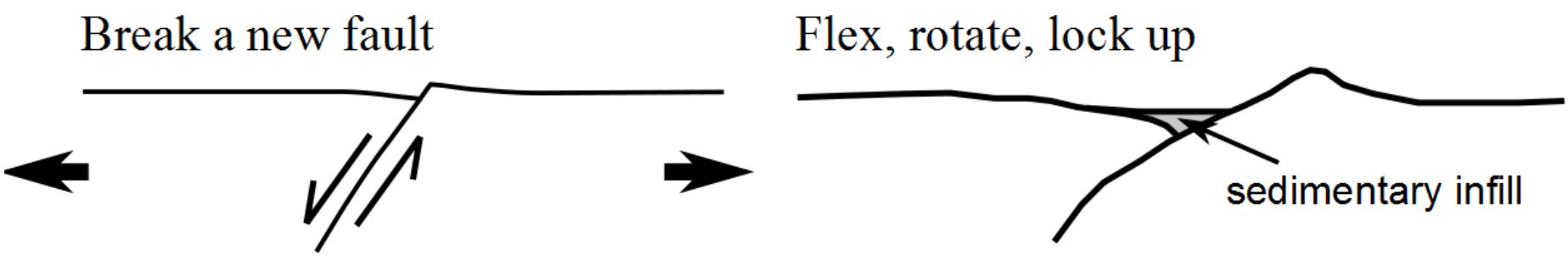
Geology (1986)

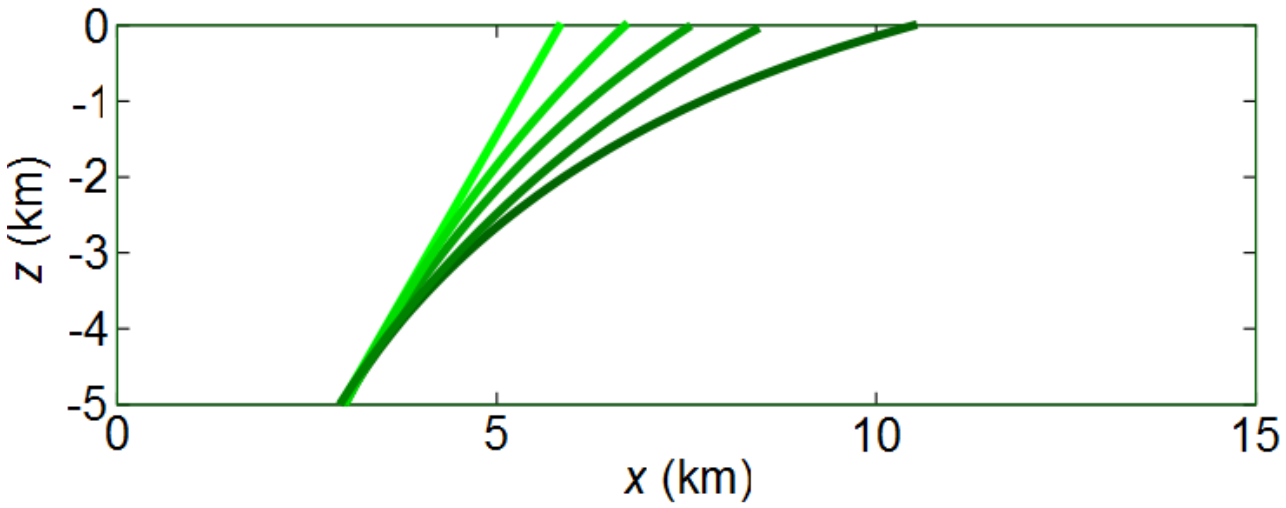


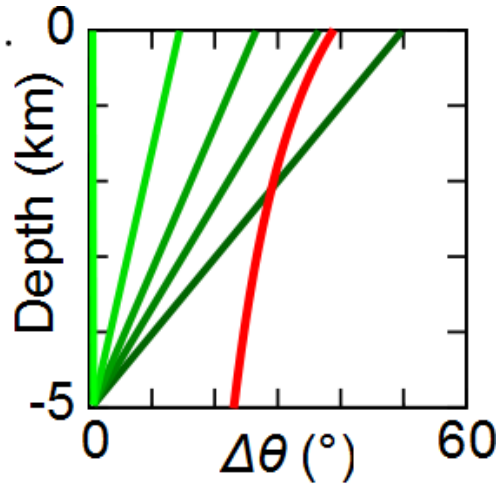
Considered how much faults can be rotated from an ideal orientation before a new fault set forms

It is more complex for dip slip faults since the stresses change with depth. Theory worked out in Choi and Buck (2012, JGR)

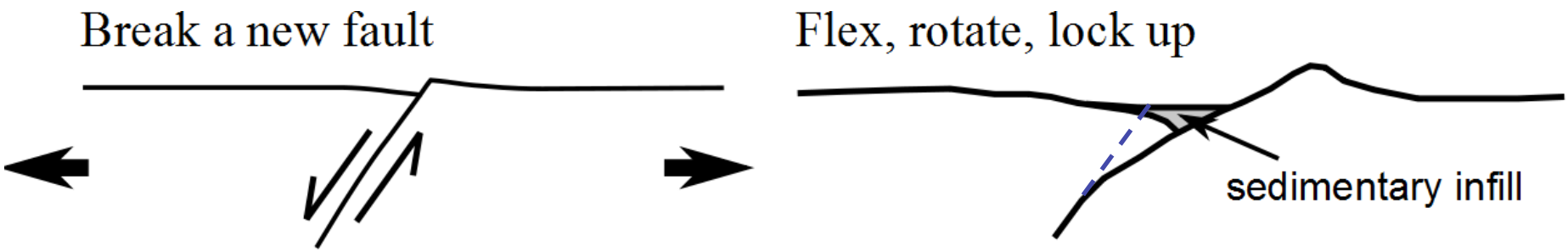


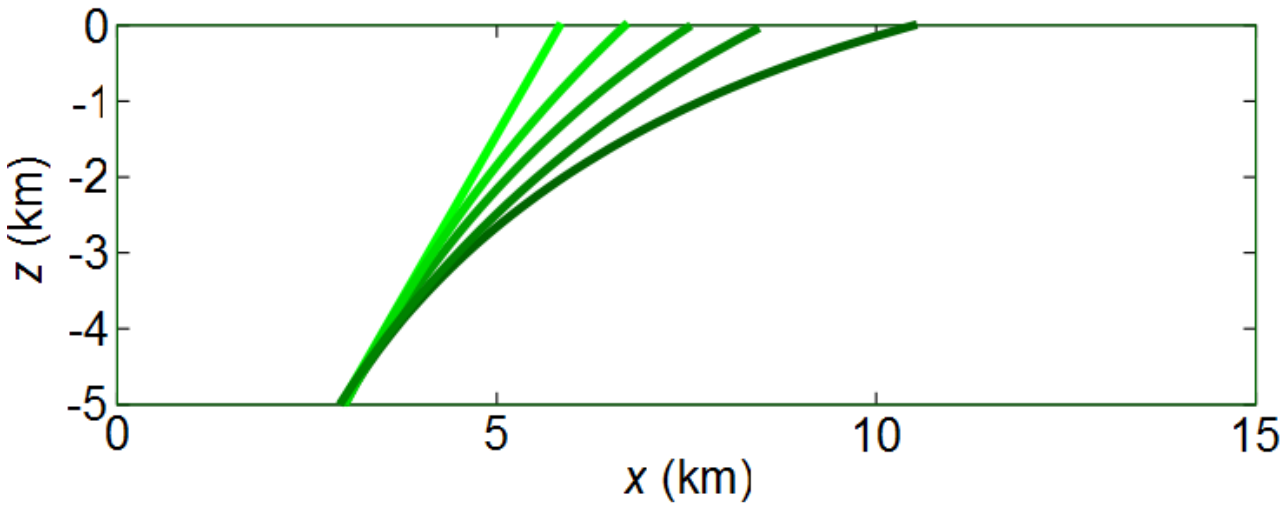


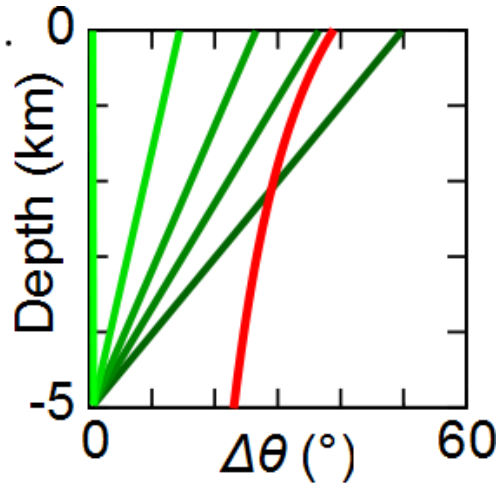




After Choi and Buck (2012)



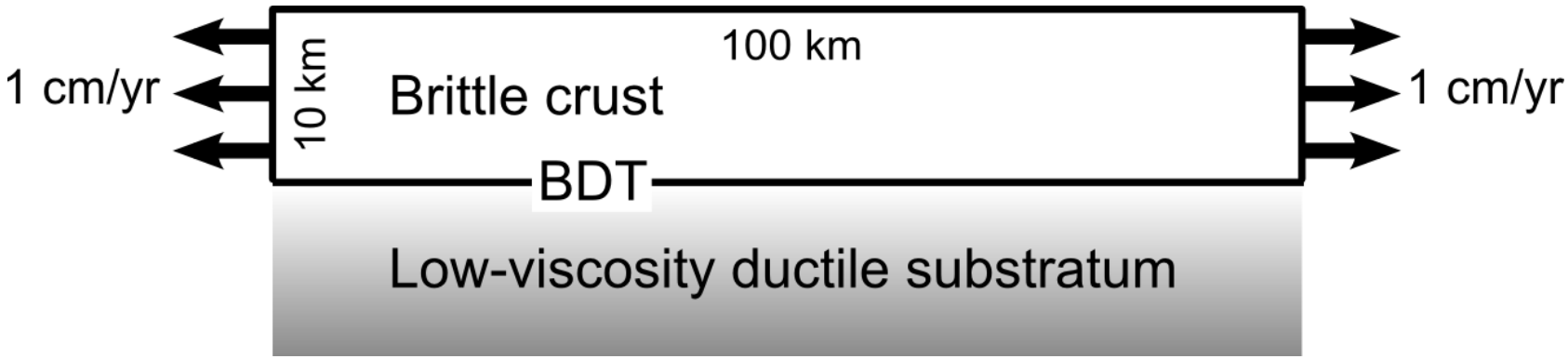




After Choi and Buck (2012)

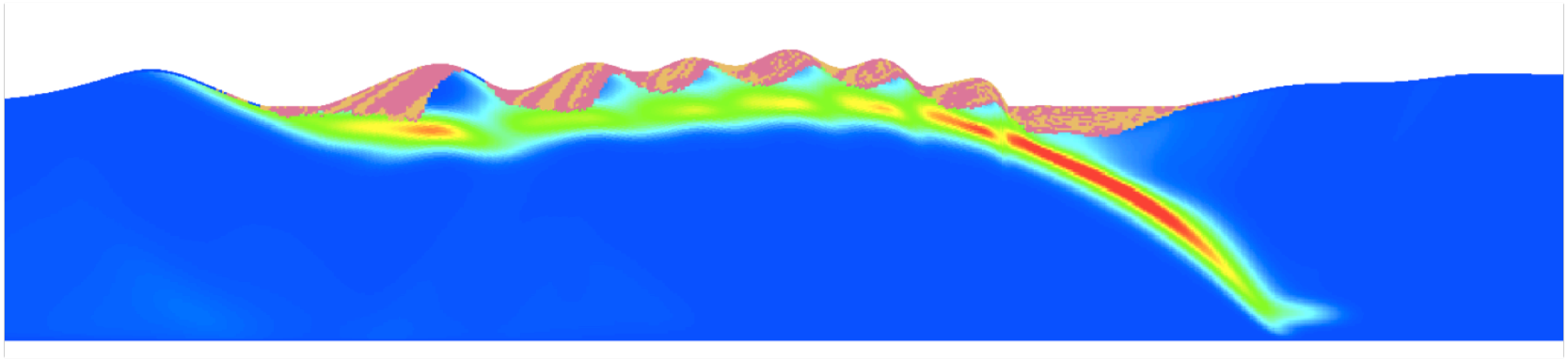
- Numerical Method: FLAC
  - **100 m** resolution for **100 km x 10 km** domain.
  - Full extension rate of 2 cm/yr, frictionless bottom support.
  - **Mohr-Coulomb** plasticity with strain weakening

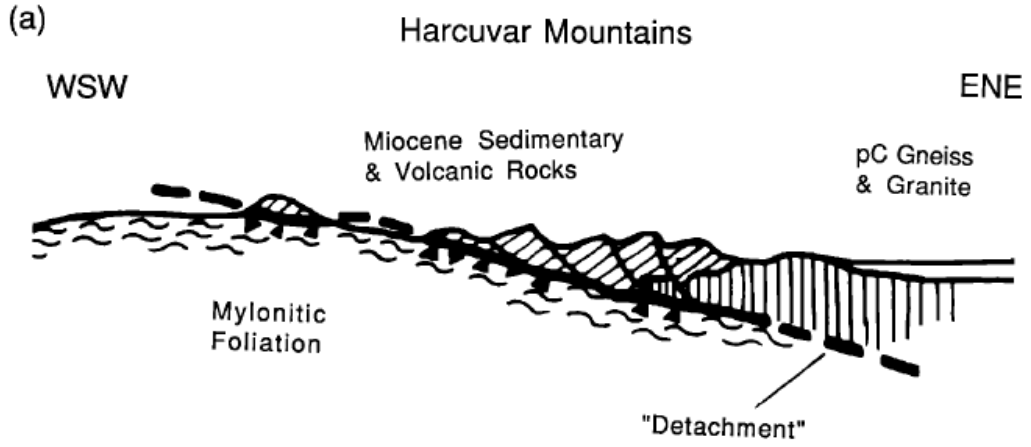
    Localized plastic strain → faults



Moderate Cohesion Reduction, No Friction Reduction, Infill to 1 km depth

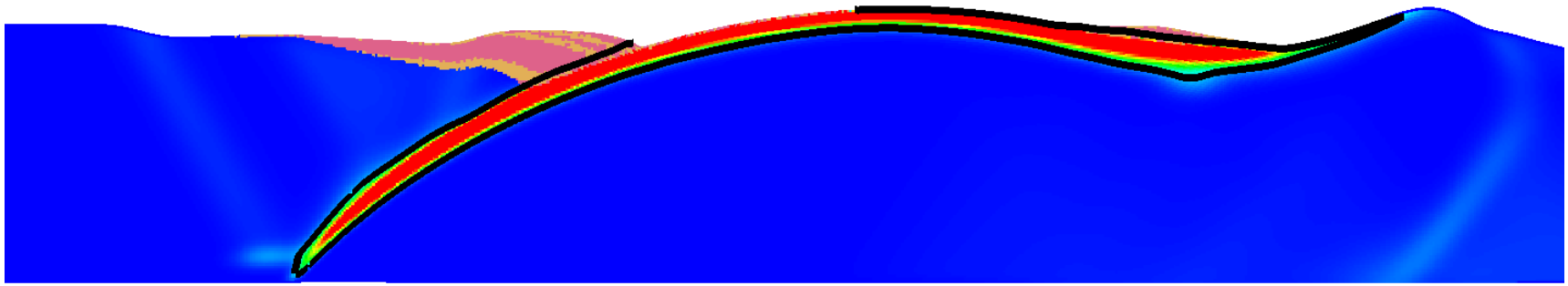
C_i=20 MPa, C_f/C_i=0.2, φ_i=30°, φ_f/φ_i=1.0.

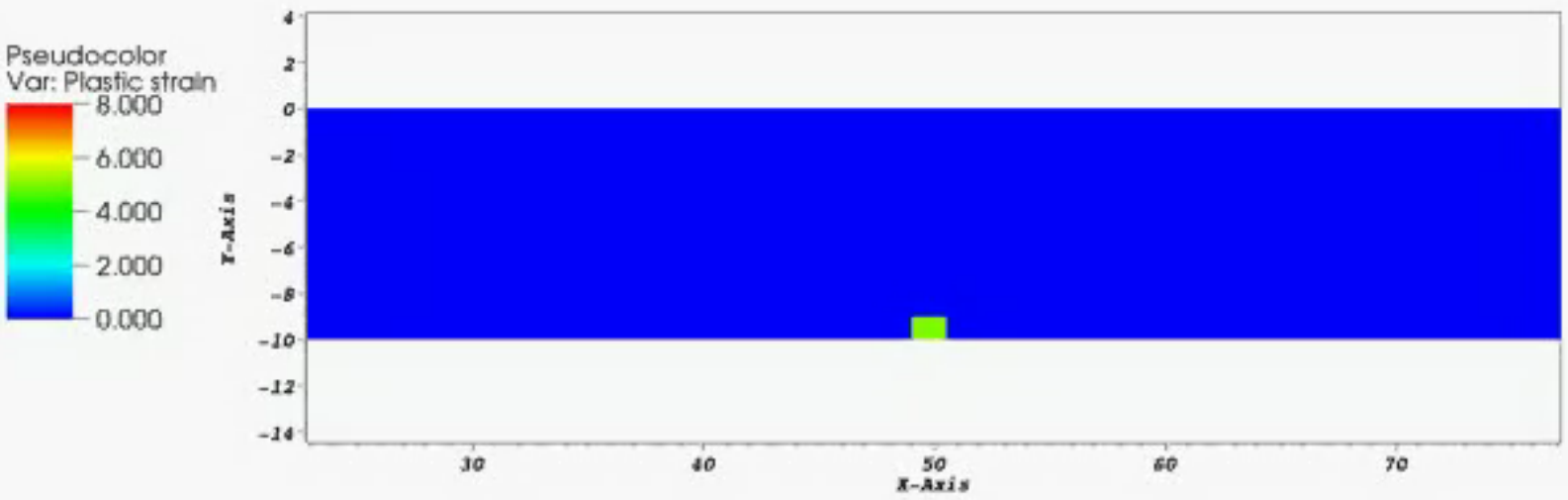




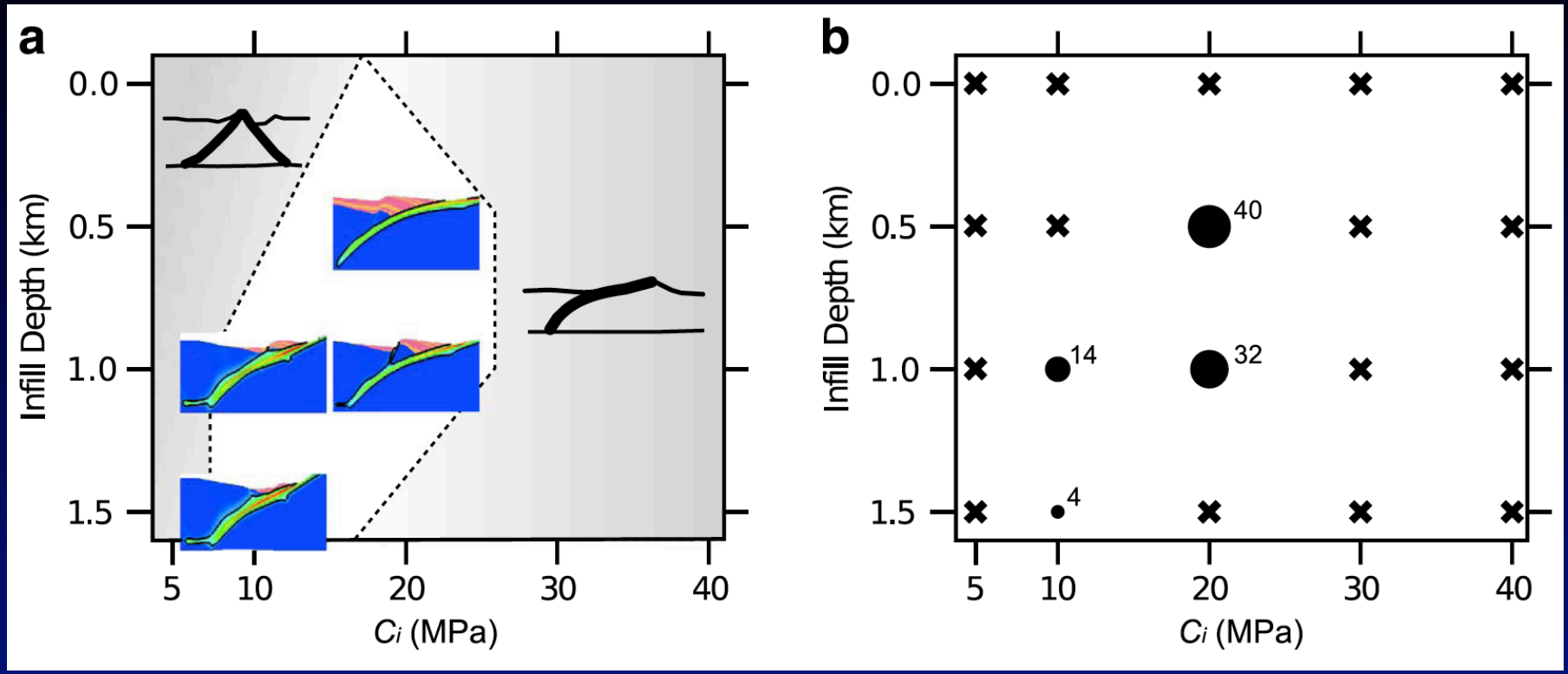
Very Weak Fault

C_i=20 MPa, C_f/C_i=0.0, φ_i=30°, φ_f/φ_i=0.7.



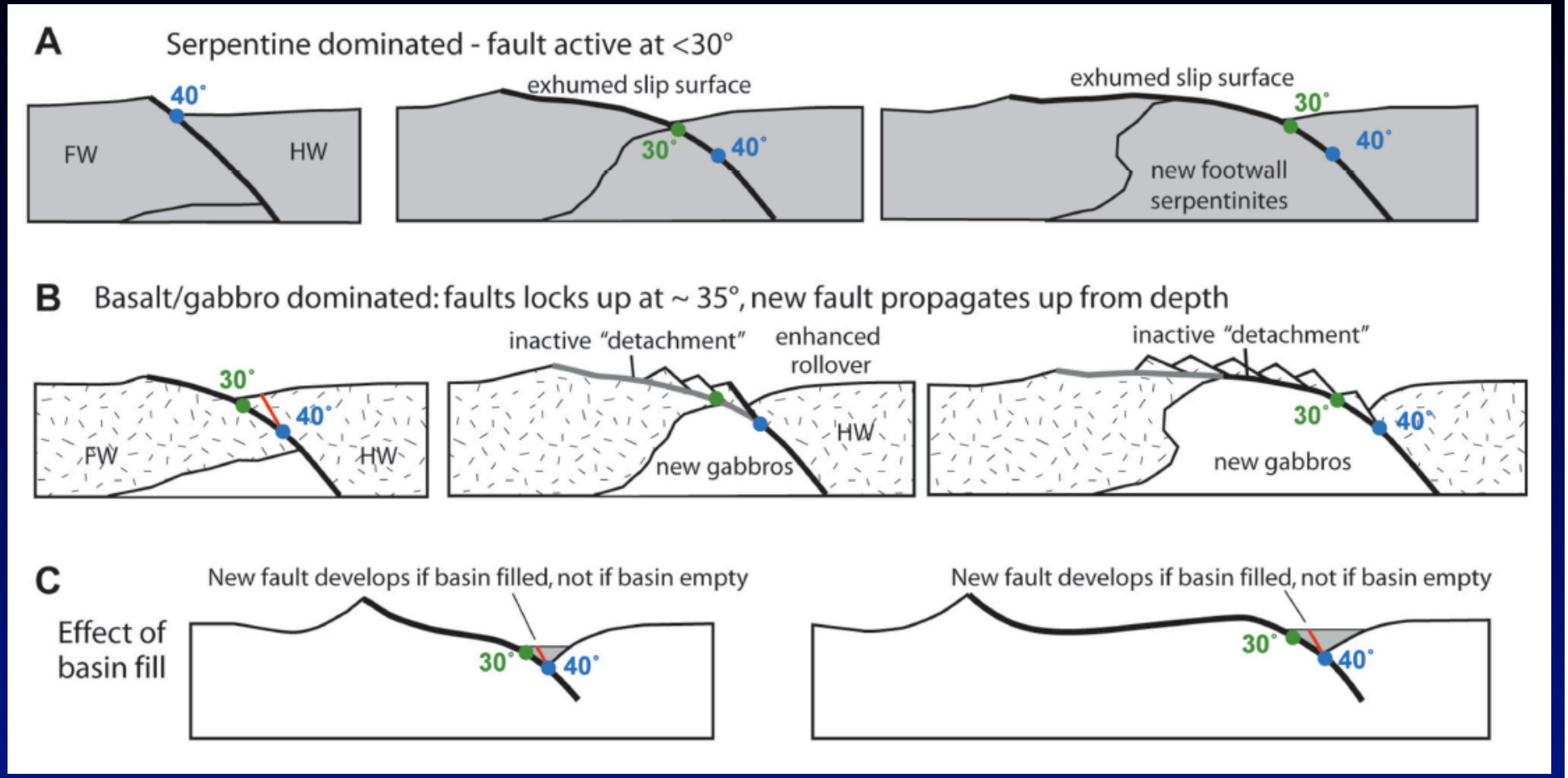

Pseudocolor
Var: Plastic strain
8.000
6.000
4.000
2.000
0.000
Y-Axis
4
2
0
-2
-4
-6
-8
-10
-12
-14
30
40
50
60
70
X-Axis

Conditions for Core Complexes Faulting with Rider Blocks



Faults cannot be too strong or too weak,
also need moderate sediment or volcanic infill

Choi, Buck, Lavier and Petersen, Geophys. Res. Letts., 2013



Reinterpretation of Reston and Ranero (2011) by Choi and Buck (2011): Reduction of friction by a factor of 2 means no rider blocks no matter how much fill.

Conclusions on Friction

Discrete rider blocks require:

1. Faults with moderately reduced cohesion (~10-20 MPa). Rider Blocks do not do not form for faults with only friction reduction or great strength reduction (cohesion + friction)

2. Moderate sediment or volcanic infilling of fault basin.