Folds

Mechanics Theory and Practice

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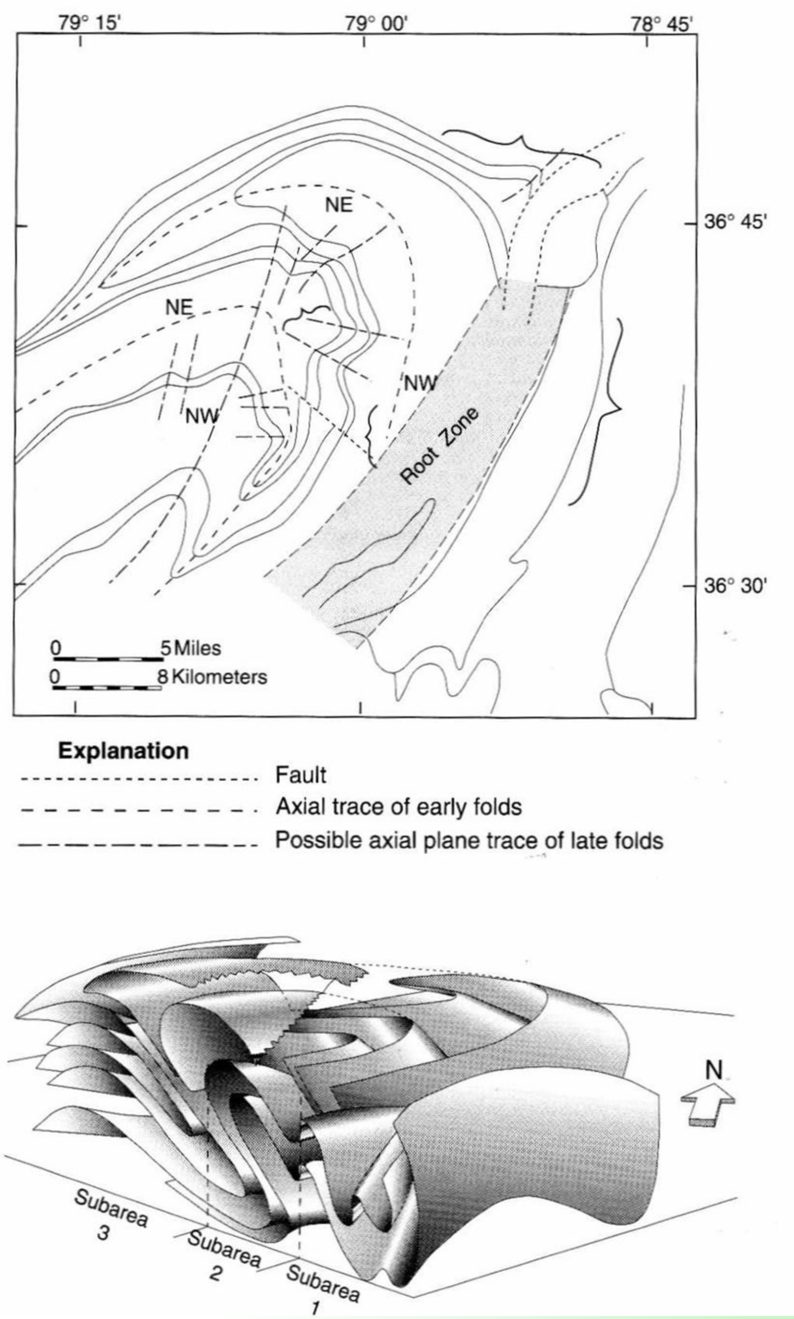
Gary Couples

May be very complex

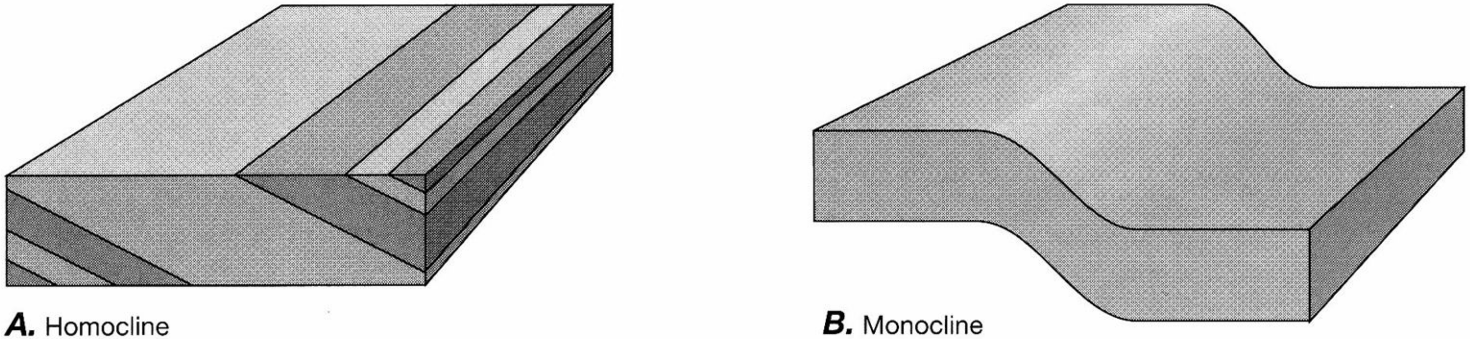


Complex fold map (top) and explanation for Milton area, North Carolina (Hatcher, 1996)

More common information

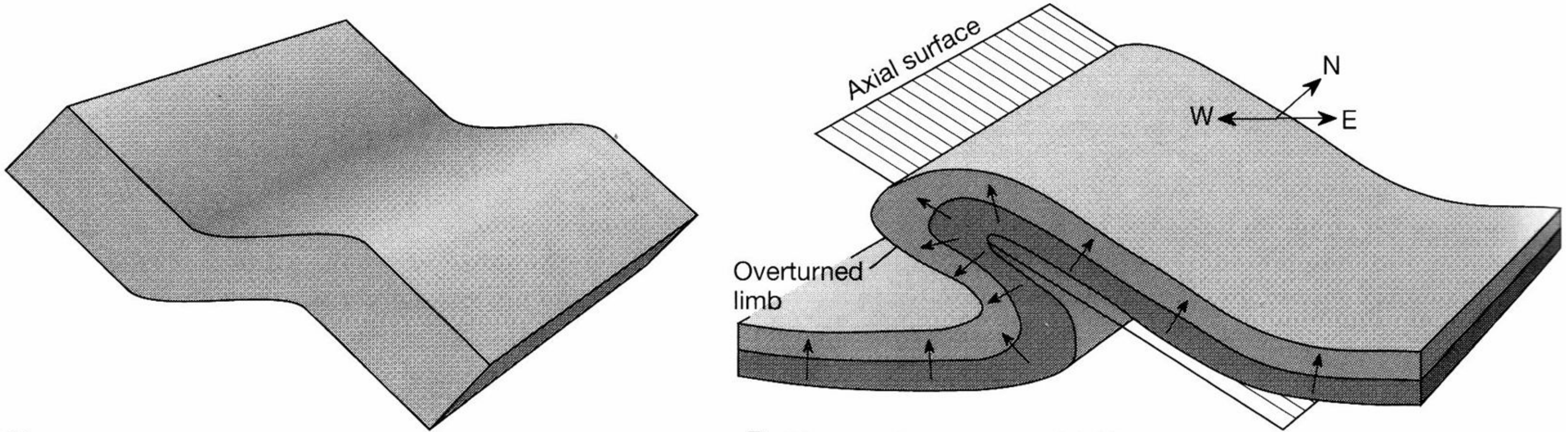
Моноклиналь в отеч. терминологии

Флексура в отеч. терминологии



A. Homocline

B. Monocline



C. Structural terrace

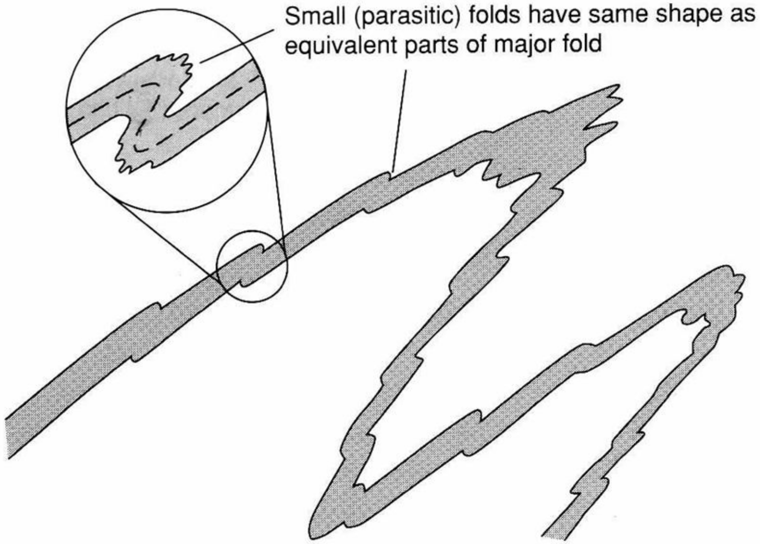
D. West verging overturned fold

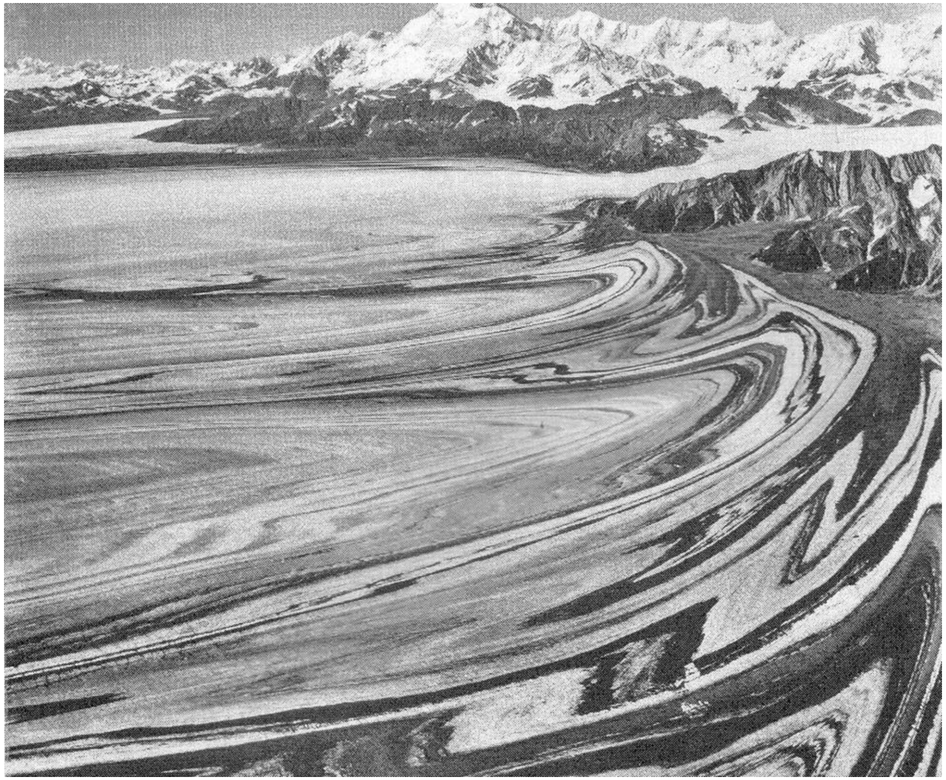
Twiss & Moores, 1992

More common information

Different order folds on the molting glacier

Hatcher, 1996

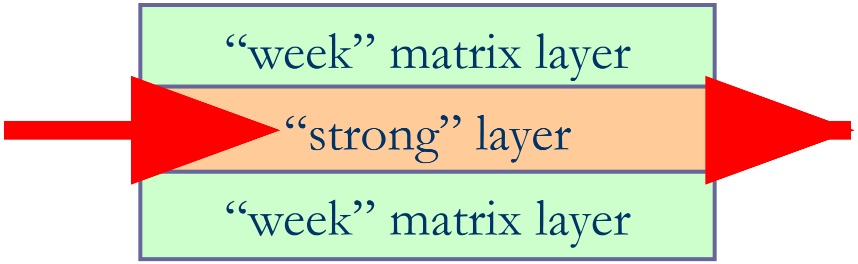




Pumpelly's rule: small-scale structure generally mimic larger-scale structures formed the same time

Folding Theories

- Buckling (продольный изгиб)
- Bending (поперечный изгиб)
  - Compactional drapes
  - Laccoliths
  - Fault-blocks
  - Salt domes
  - etc



“week” matrix layer

“strong” layer

“week” matrix layer

$$\lambda_d = 2\pi t \sqrt[3]{\frac{\mu_1}{\mu_2}}$$

were:

λ_d - dominant wavelength of the “strong” layer,

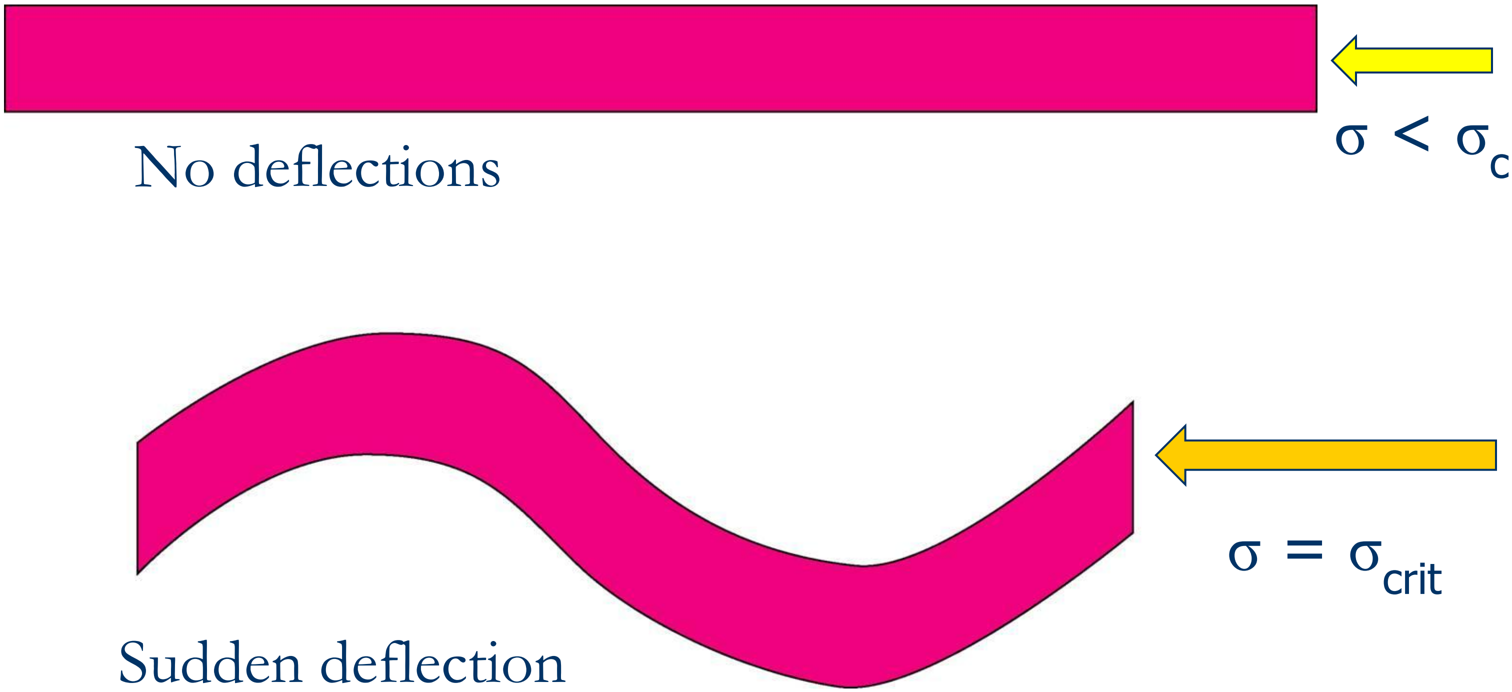
t – thickness of “strong” layer,

μ_1 – viscosity of the “strong” layer,

μ_2 – viscosity of the supporting matrix of “week” layers

Single-Layer Buckling

Layer is surrounded by a “medium”



No deflections

$\sigma < \sigma_{crit}$

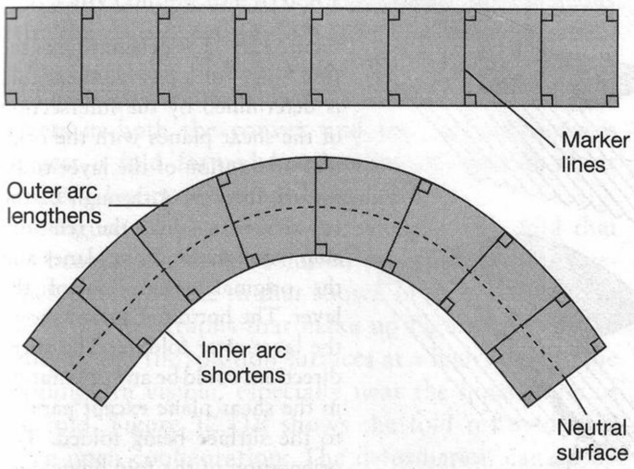
$\sigma = \sigma_{crit}$

Sudden deflection

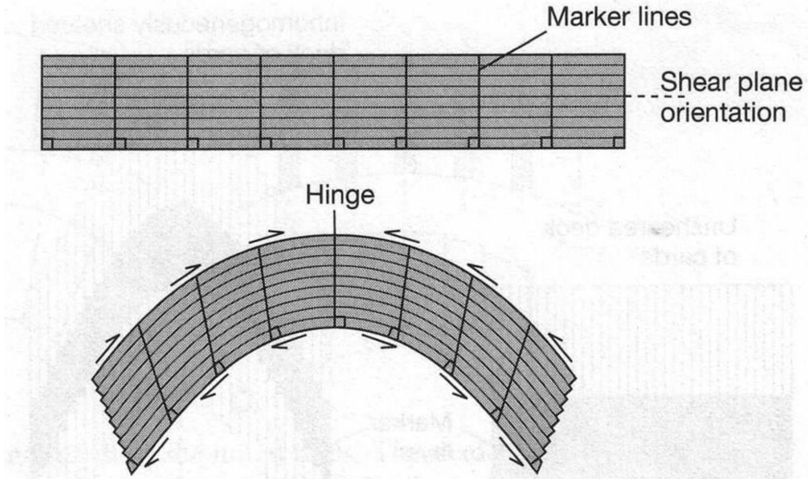
s_{crit} = f (thickness, ratio of stiffnesses)

Basics of Folding Mechanics

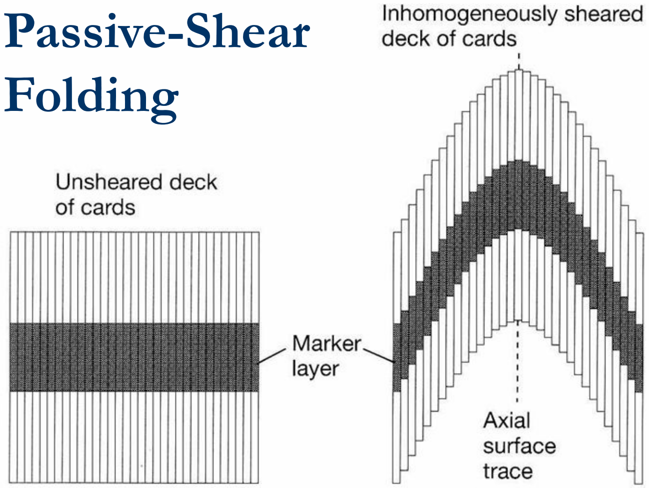
Ortogonal Flexure



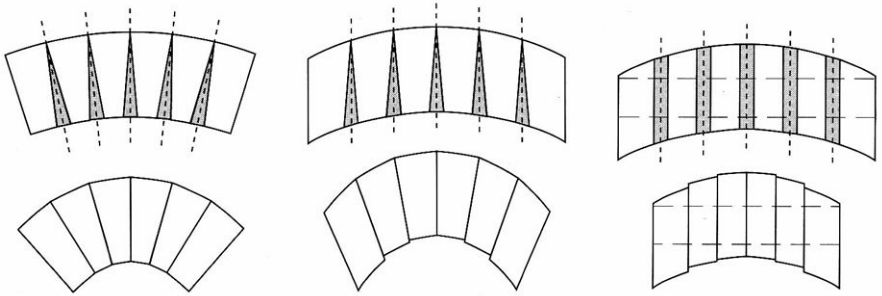
Flexural-Shear Folding



Passive-Shear Folding



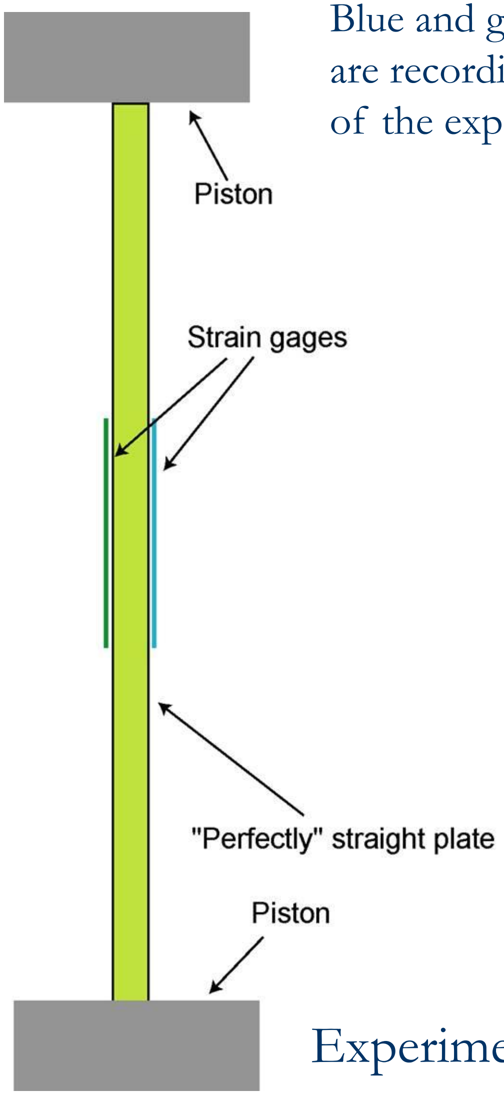
Volume-loss Folding: compressional solution bends formation!! – кливаж осевой поверхности

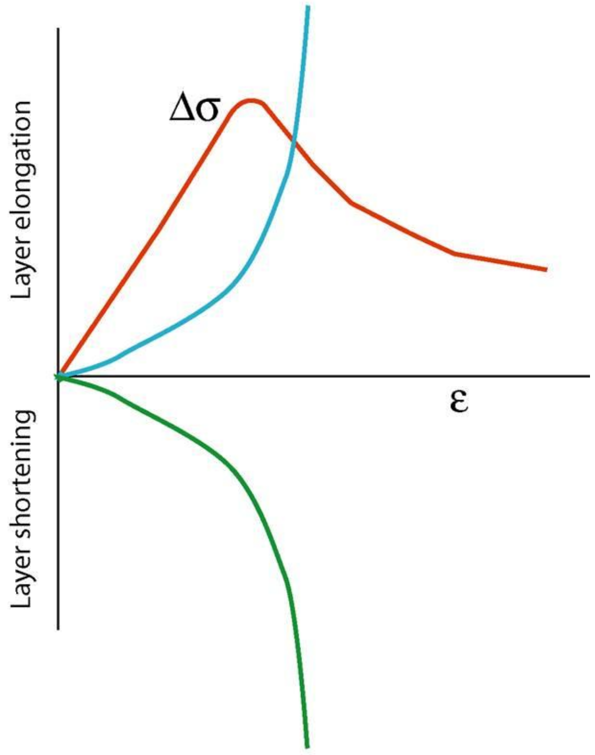


Twiss & Moores, 1992

“Buckles” in the Laboratory

Blue and green curves show that strain gages are recording deflections from the beginning of the experiment





These experiments reveal that EVERY plate tested begins to deflect from the instant that load is applied.

Yes, there is an accelerated deflection that occurs near peak load.

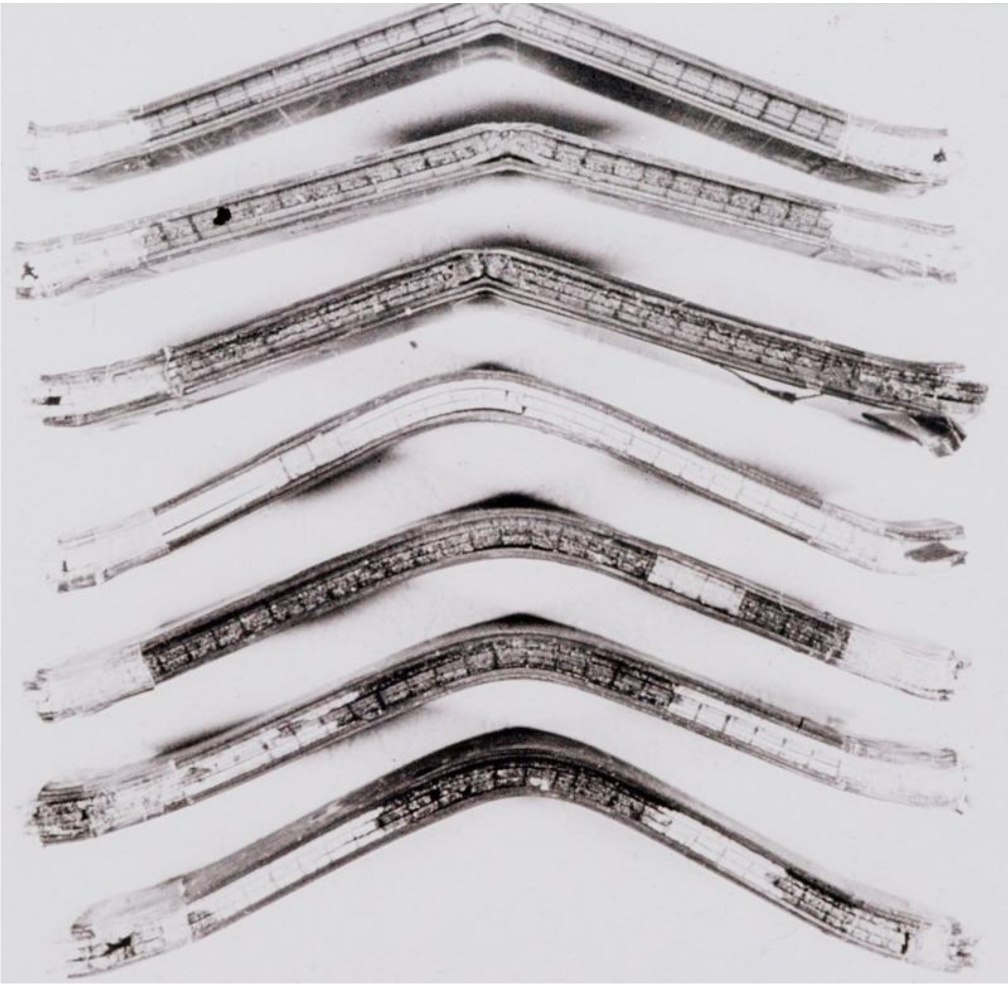
But these results do not support the notion of buckling.

Experimental work by Mike Fahy, 1974-76

But Pushing on Rock Layers Makes Folds

These rock-layer models were deformed at confining pressure as a consequence of layer-parallel shortening.

The different fold shapes are related to differences in lithology and confining pressure.

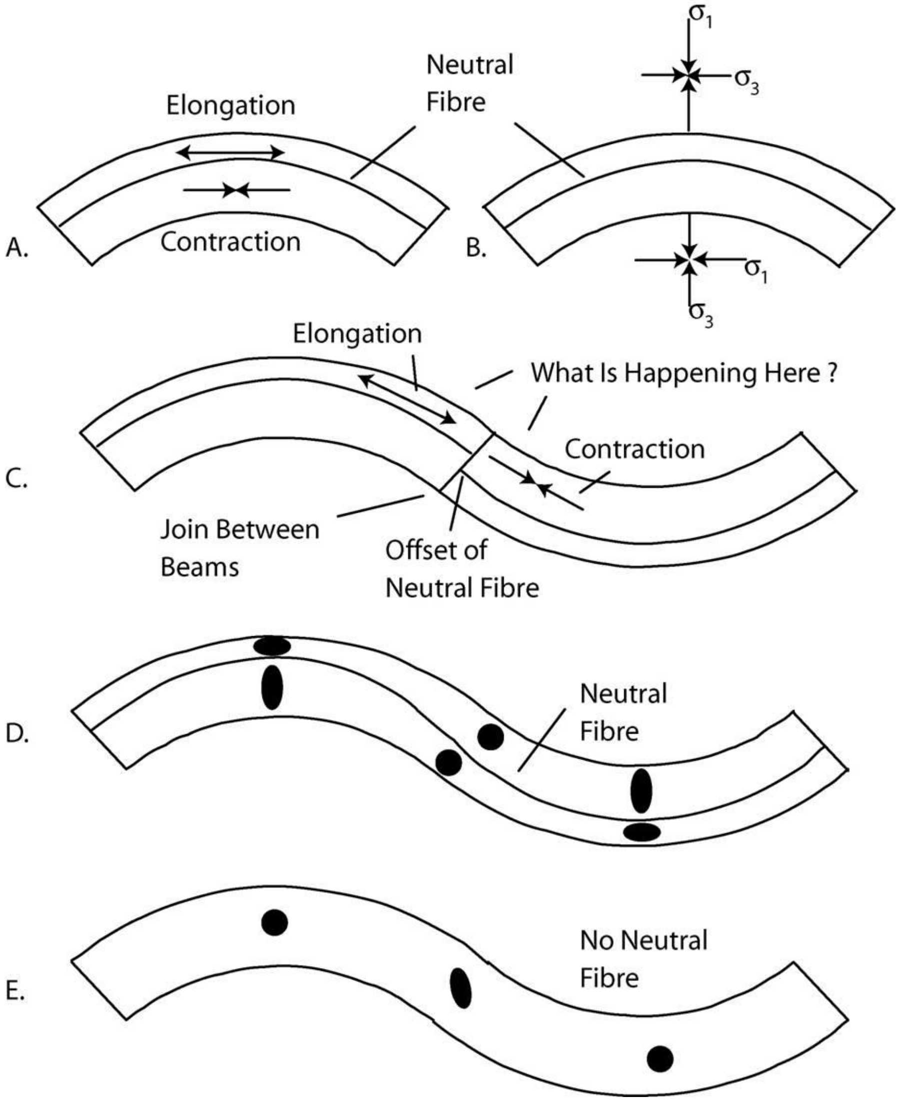


Layers originally 20 cm long (after Handin et al, 1972)

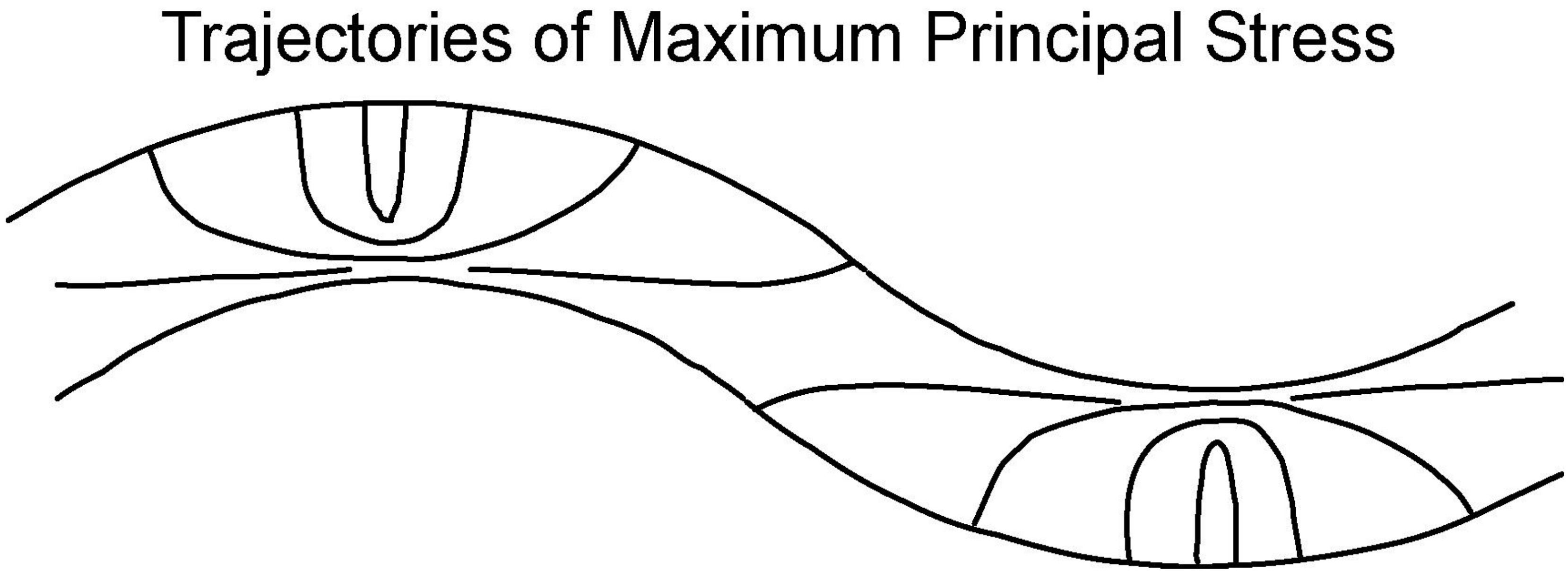
Strain Patterns

Simple conceptual models derived from observations of simple "free" beams, and extrapolation to realistic flexures

Unfortunately, these ideas aren't supported by observations



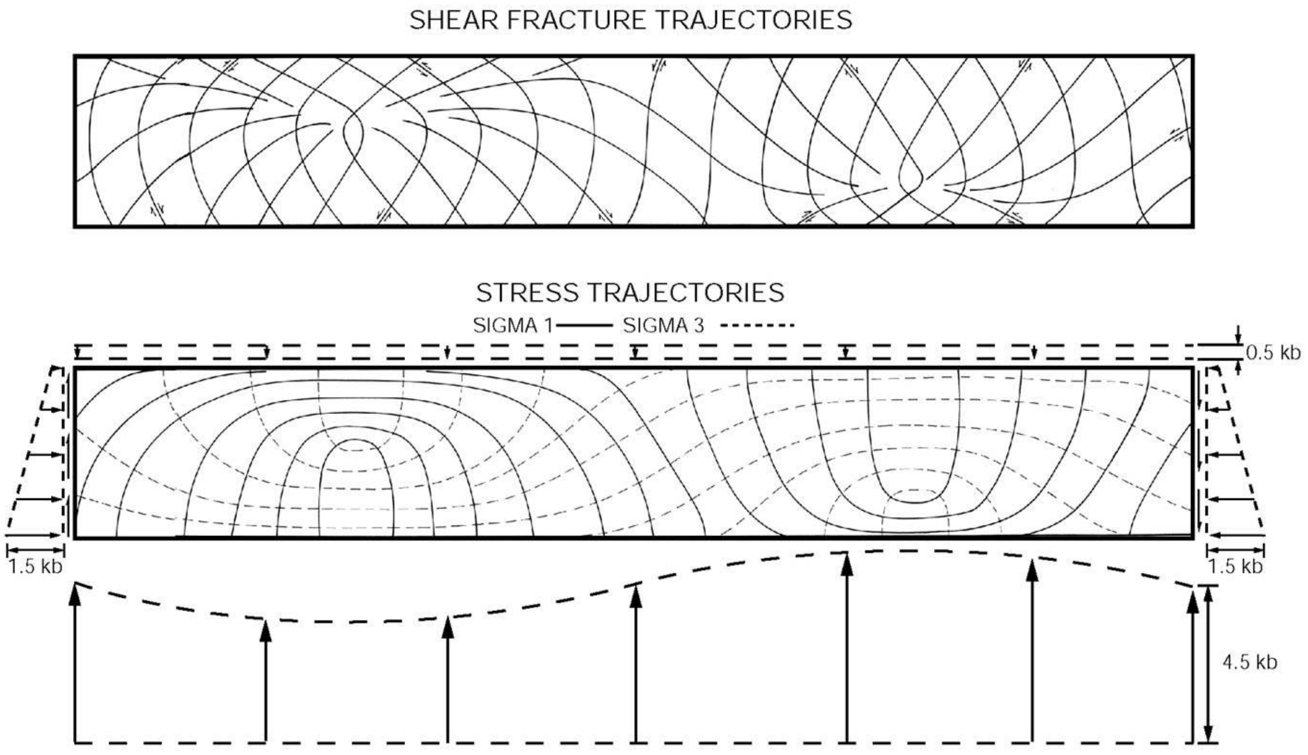
Bending Stress State



Derived from multiple sources: elasticity, photo-elastic models, physical models, outcrops, numerical simulations

Map this solution onto finite flexure

Pure Elastic Solution



LOAD SUMARRY

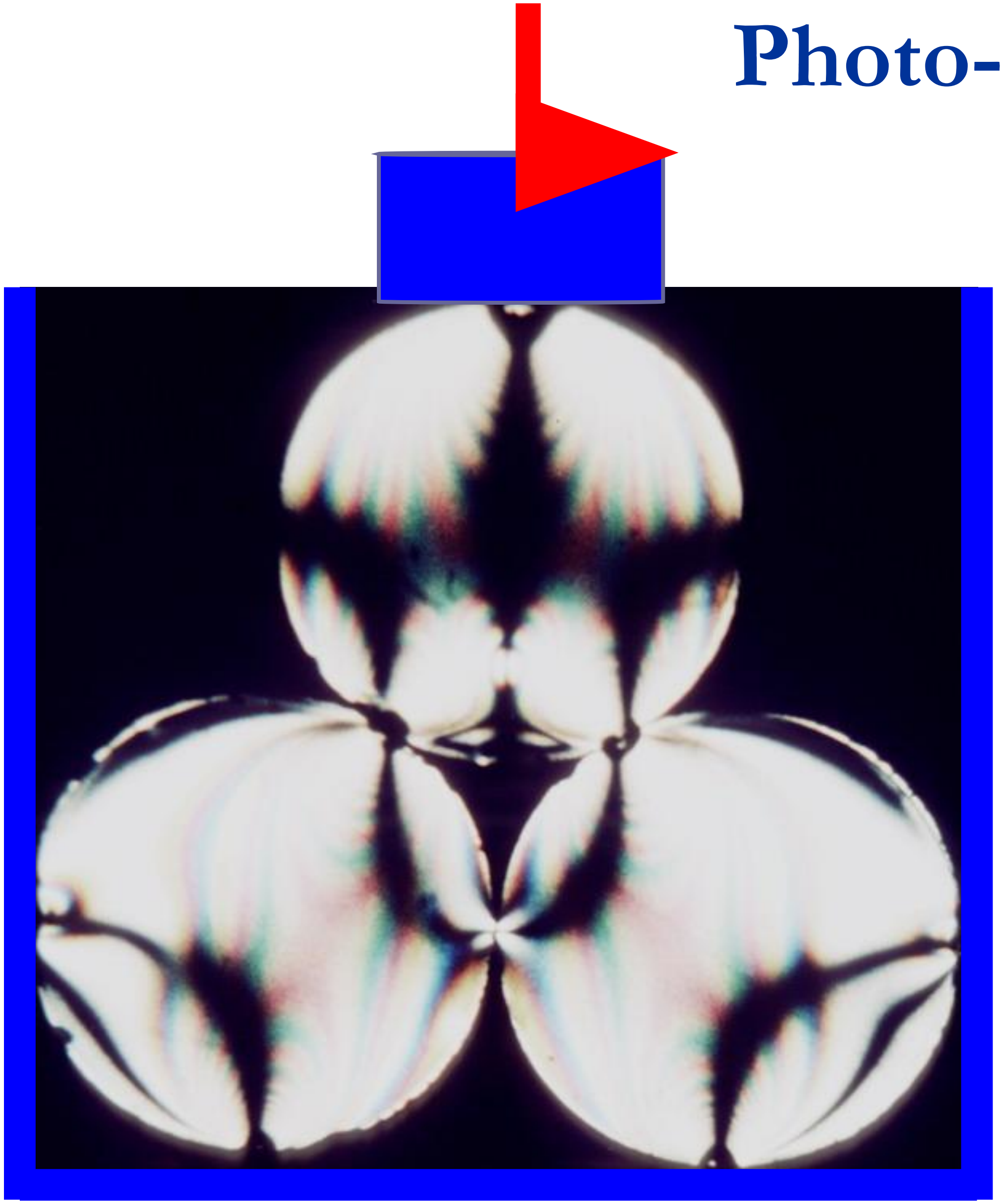
1. LOWER BOUNDARY - SIUSOID WITH ± 1.0 kb DEVIATION
2. NO TECTONIC END LOAD IN ADDITION TO STANDARD STATE
3. NO SHEAR ALONG BASE

BLOCK DIMENSIONS

100km. x 15km.

(after Hafner, 1951; Couples, 1977)

Photo-Elastic Models



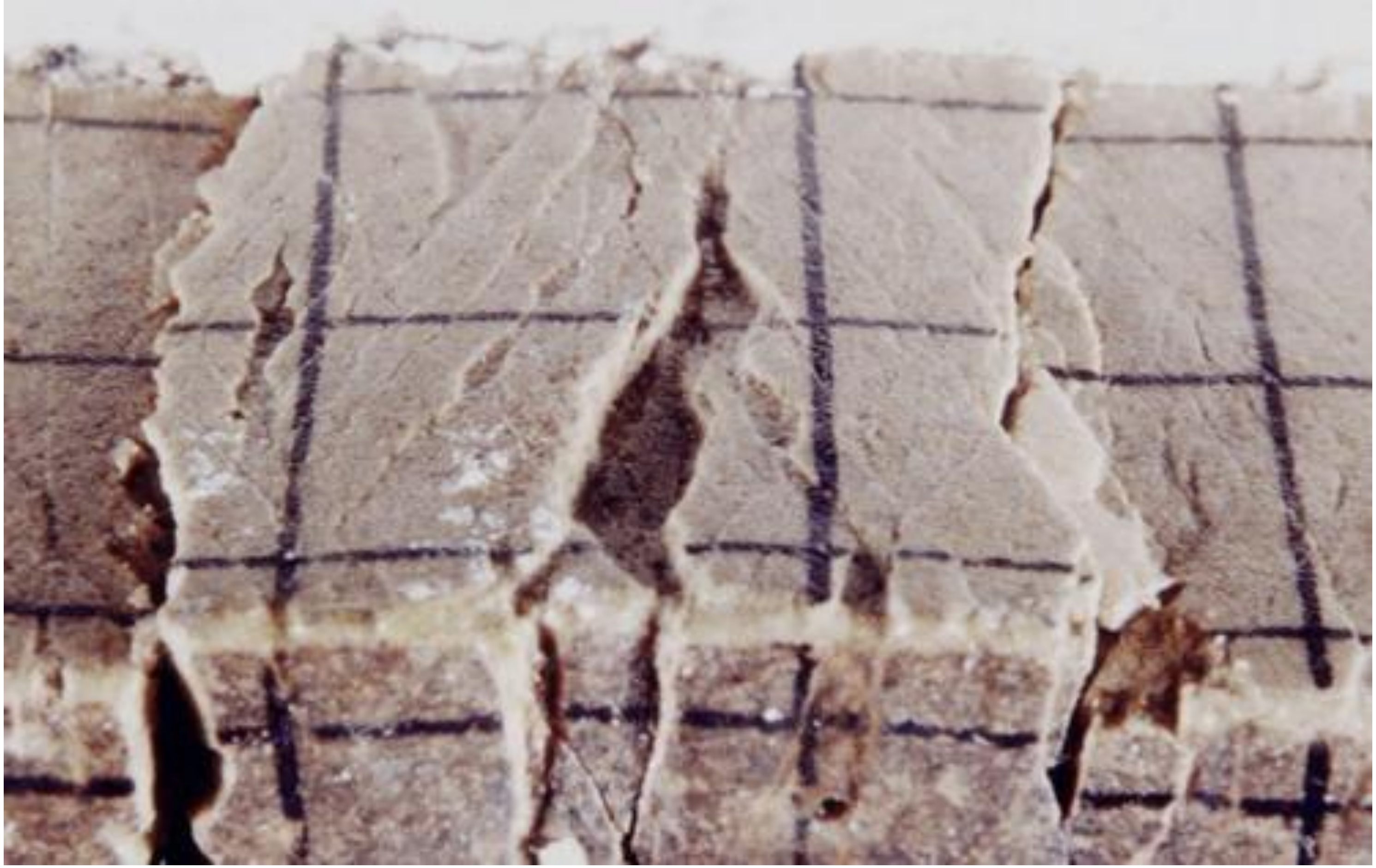
Gelatine balls: located in the glass with a piston on the top. Black bands visible in polarized light, indicate σ_1 axe trajectories

This image illustrates the method – but it is not a fold!

Using a gelatin material, and subjecting it to a deformation (an elastic one, even with high strains), we determine stress directions and magnitudes.

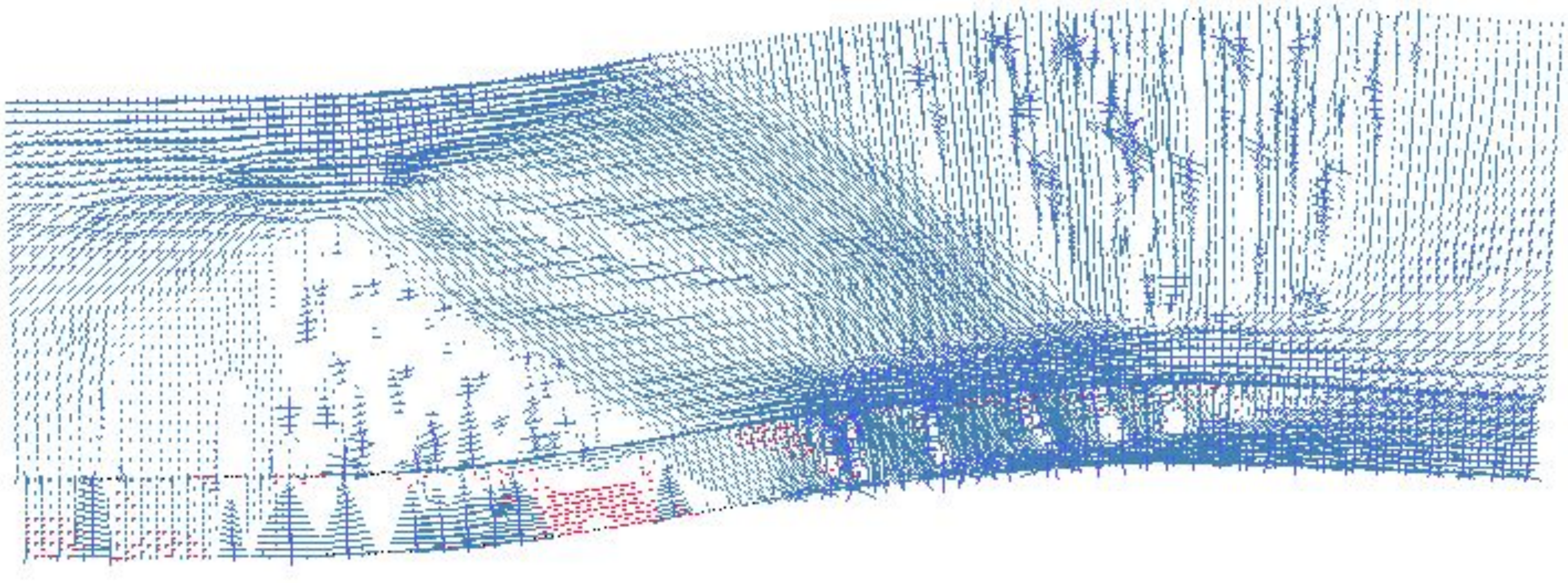
Rock Model Studies

Crest of anticline in buckled single-layer of Leuders Limestone

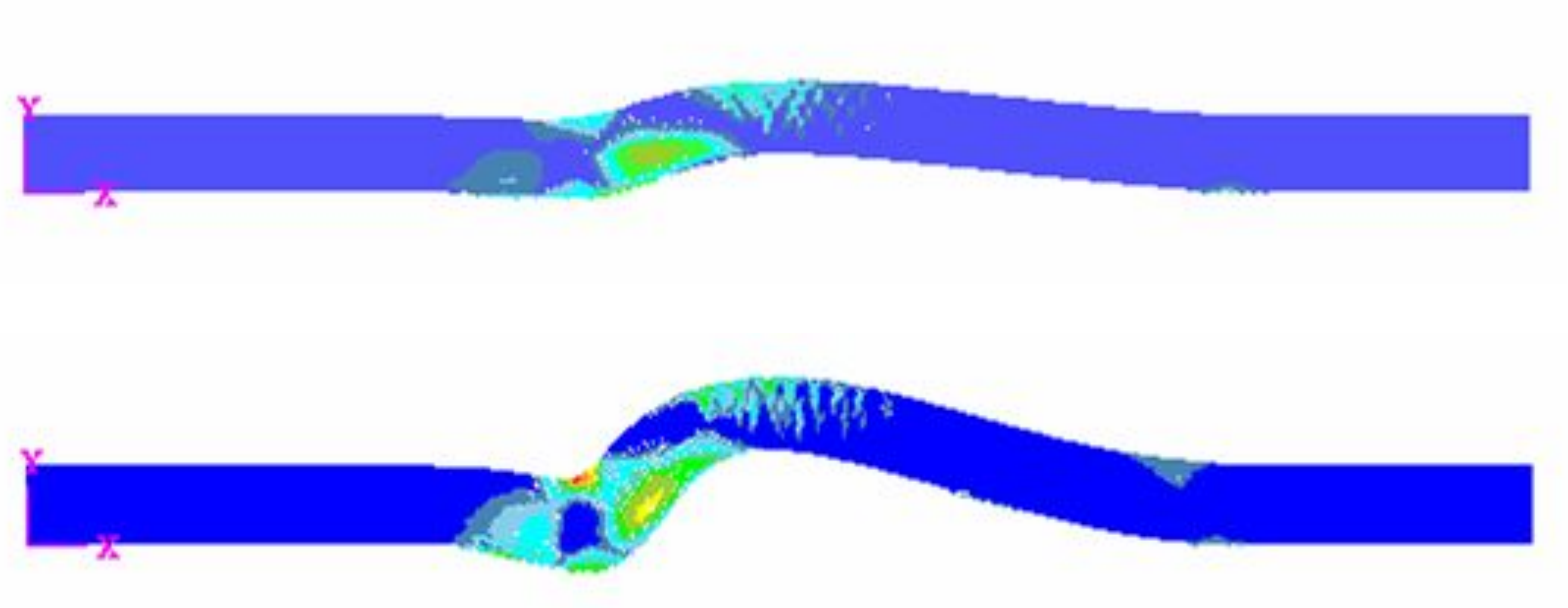


Note pattern of induced fractures (after Mel Friedman, ca. 1971)

Stress Pattern in Numerical Model of Flexure



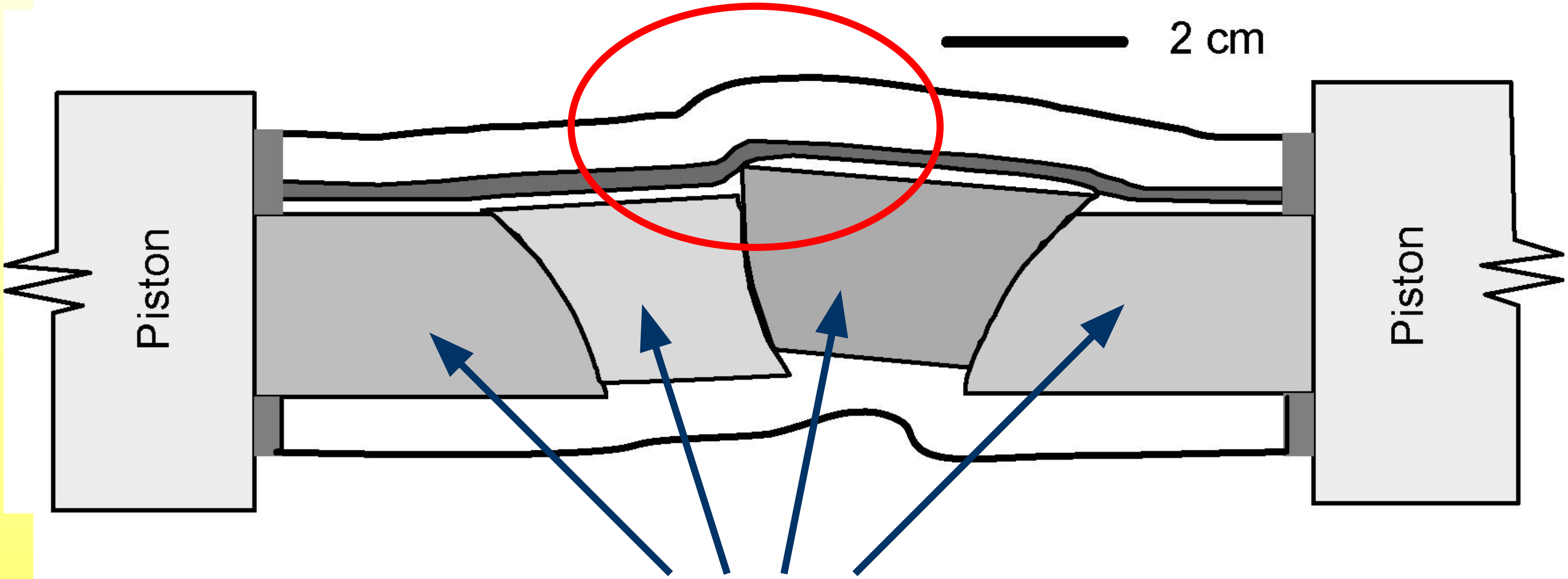
Same Pattern in Numerical Models of Buckle Folds



Testing the Flexural Model

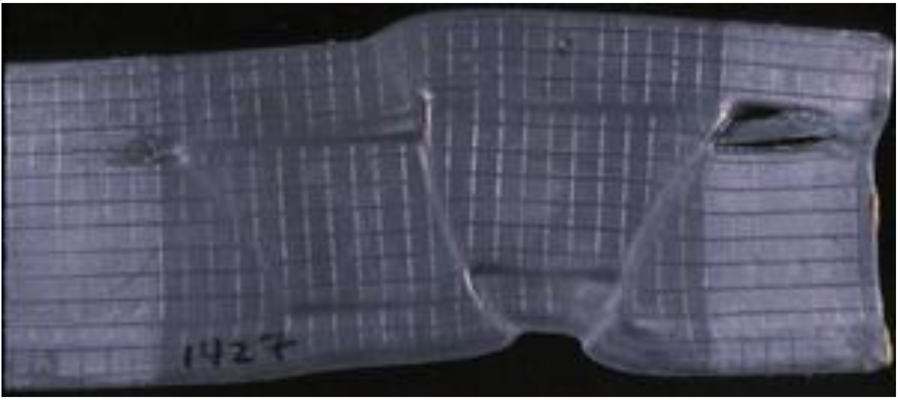
- Experimental models
- Numerical simulations
- Field observations
- Derive general prediction for fracture/ damage distributions in flexural deformations (folding)

Another Model Design: Details



Machined steel blocks: perfect circular arcs, lubricated

Examples of Specimen Data



Side jacket of lead, with scribed grid that records displacement during experiment

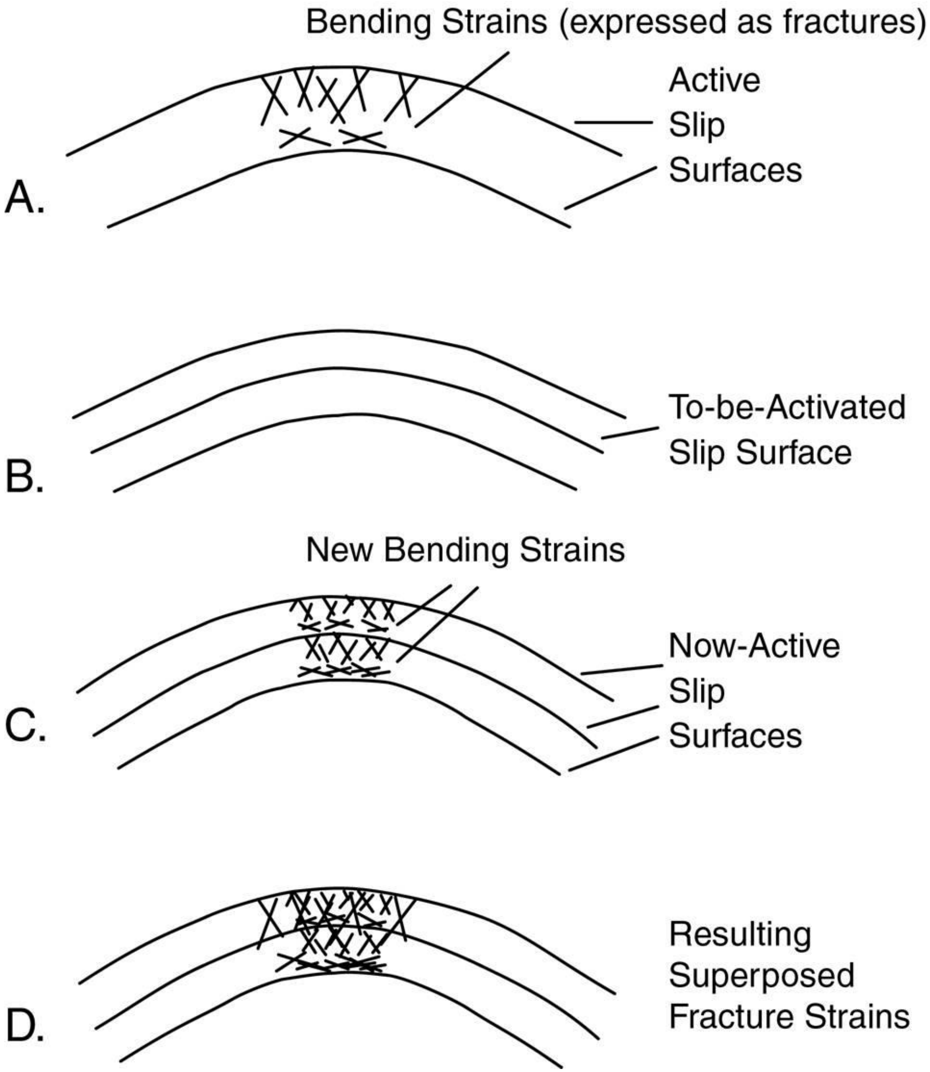
Model after epoxy impregnation and cutting on rock saw

Inside of opposite lead side jacket, showing that it was welded to sample during deformation

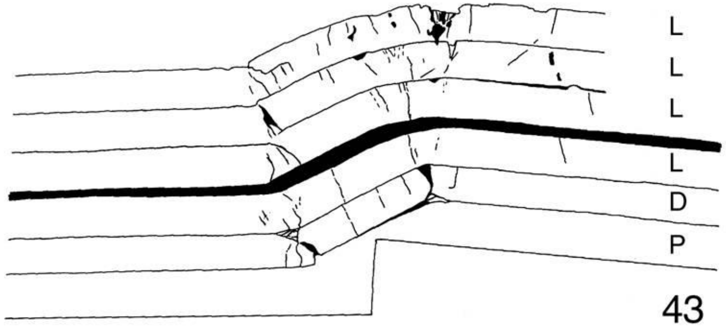
Effects of Multiple Layers

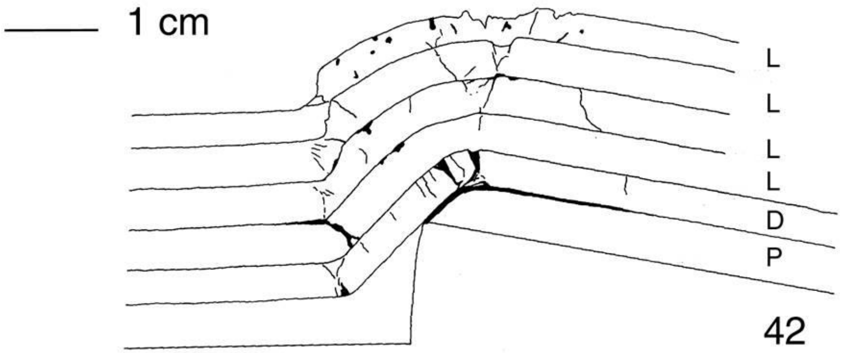
As bedding-plane slip activates, pre-existing fabric elements are abandoned, and new ones form

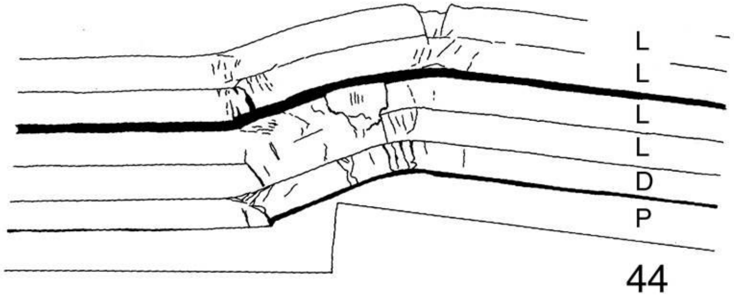
The new fabrics overprint the old, and they indicate bending within new multi-layer packages defined by the active slip surfaces

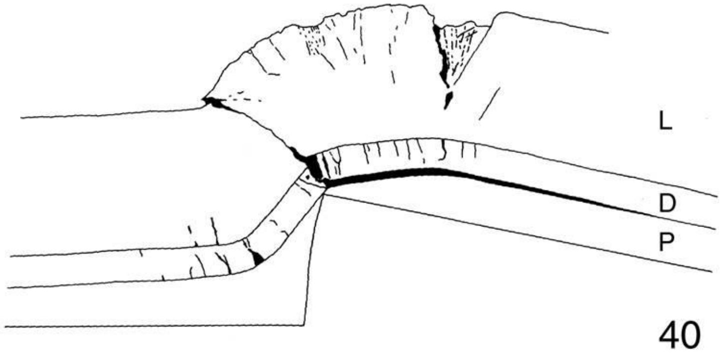


Observed Fabrics





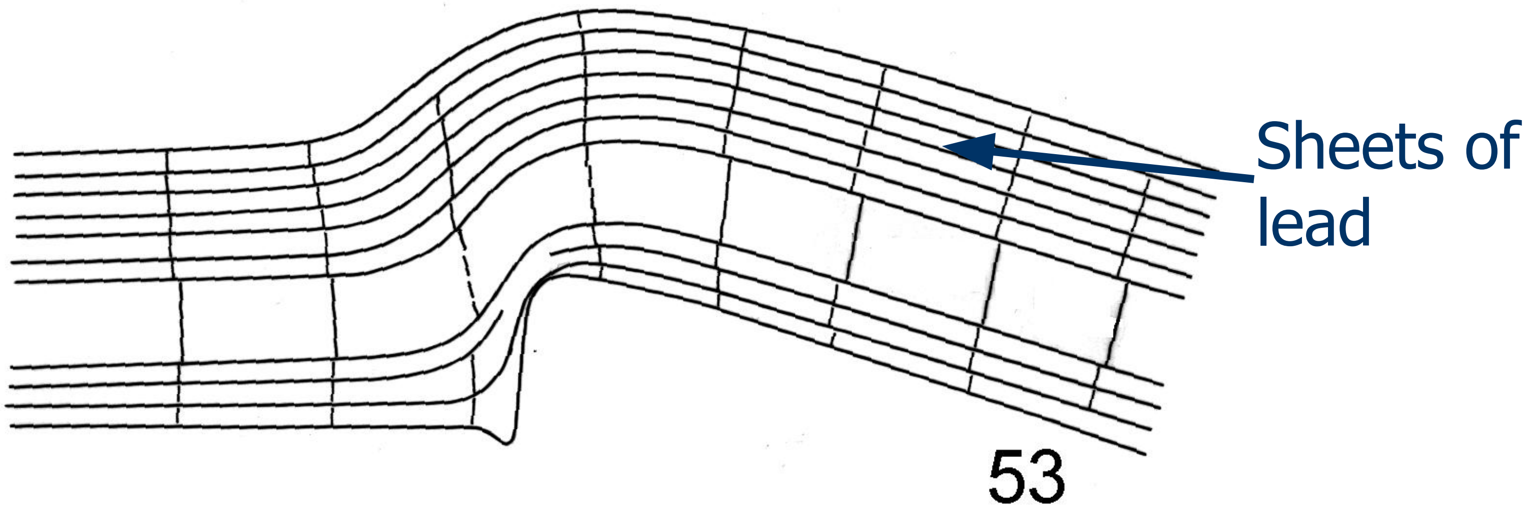


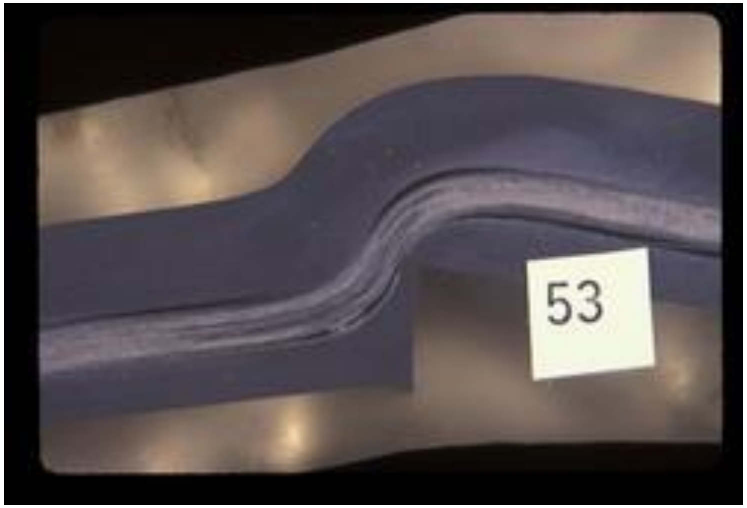


L=limestone,
D=dolostone,
P=lead

Flexural slip modifies the locations and amounts of induced damage

Multiple Beams Develop

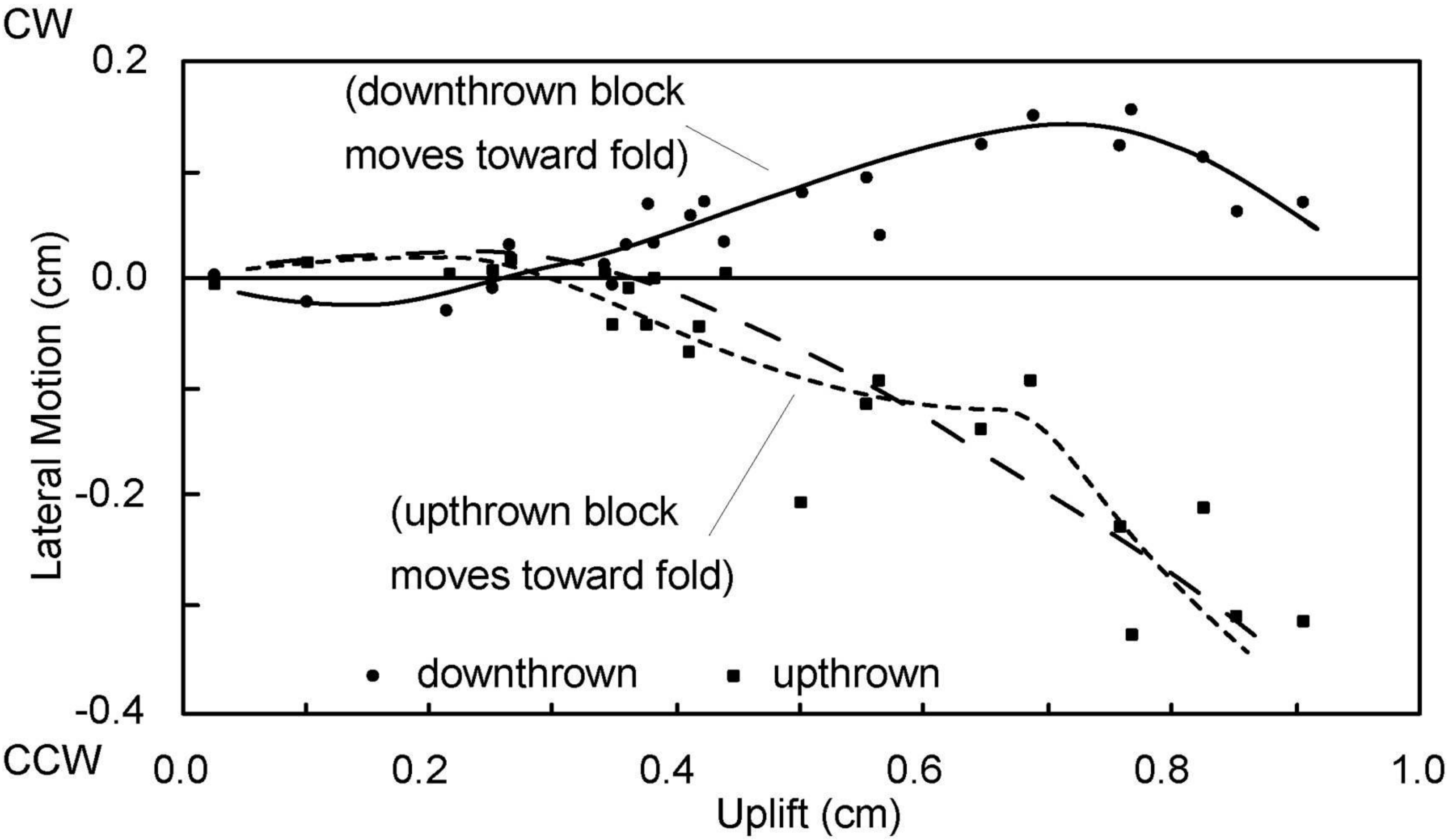




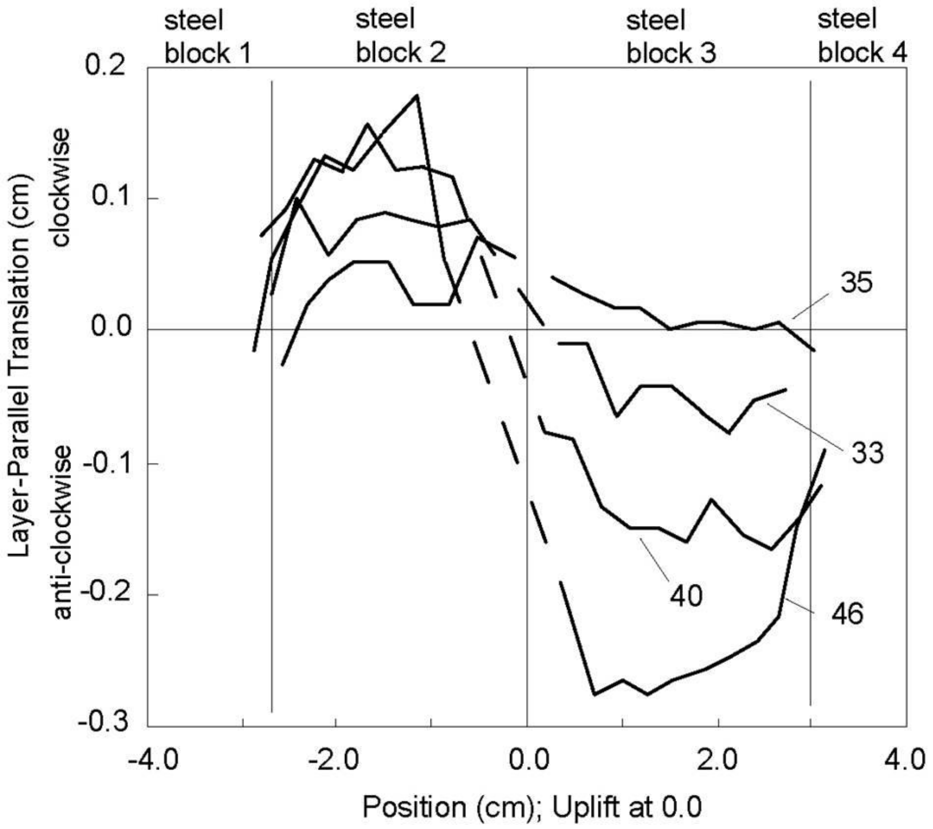
Stack of paper cards, lubricated with graphite dust

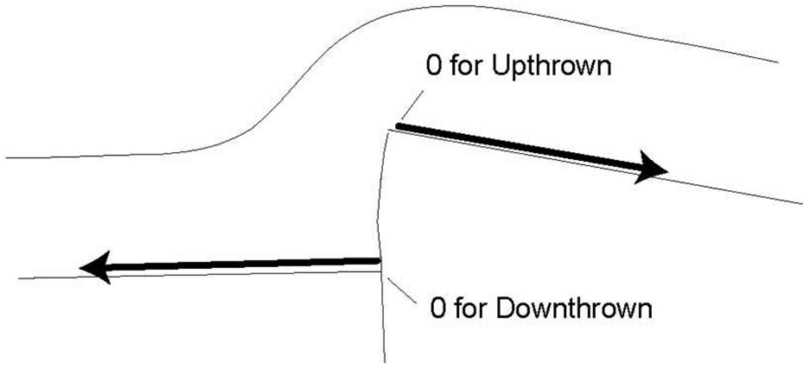
Slip develops only on some interfaces – as needed

Translations of Layers



Not Uniformly!





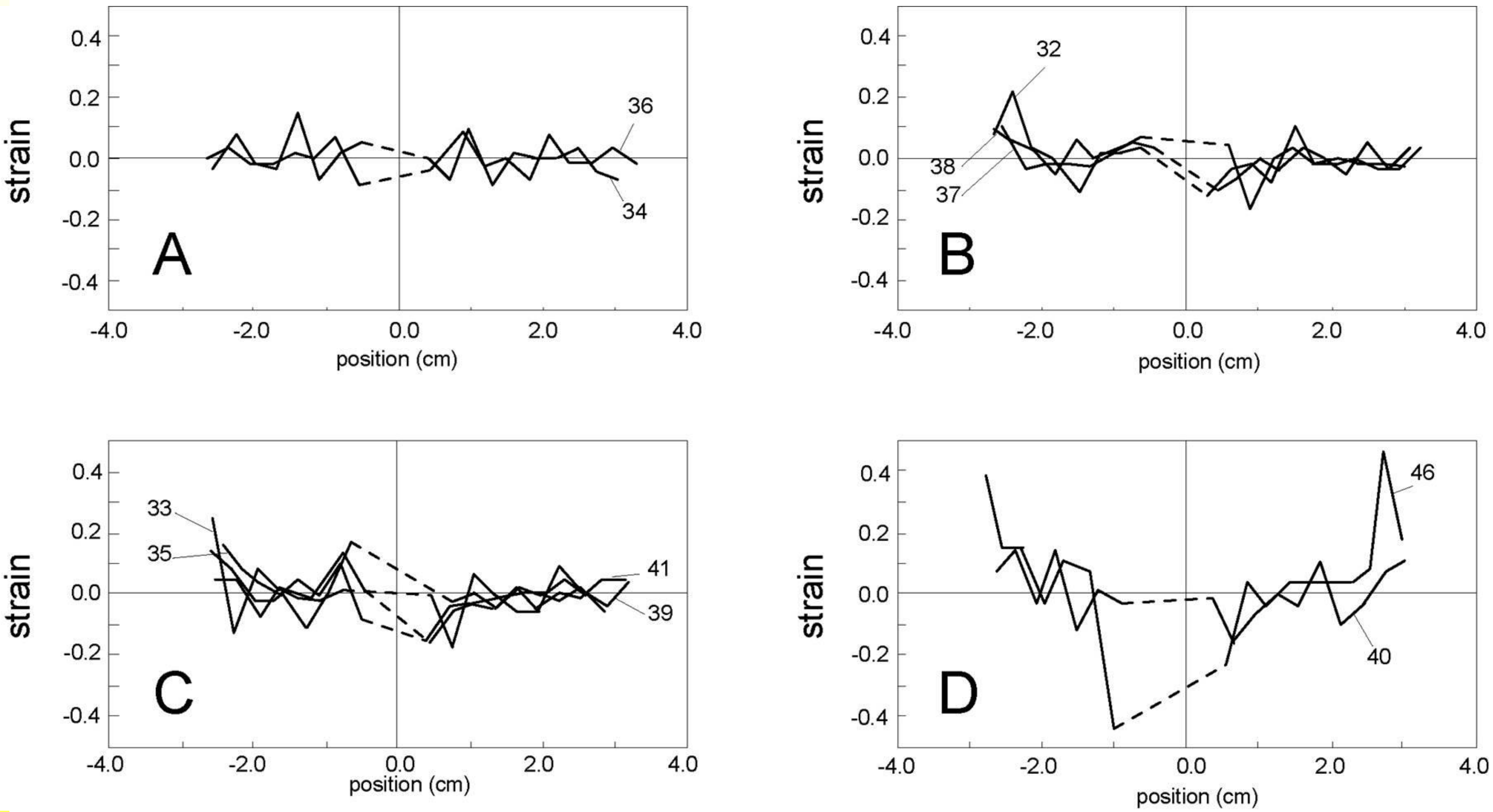
Derived from distorted grids

The rock layers move away from, and towards, the fold – all by themselves!

Lateral movement is part of the energy re-distribution operating in flexures

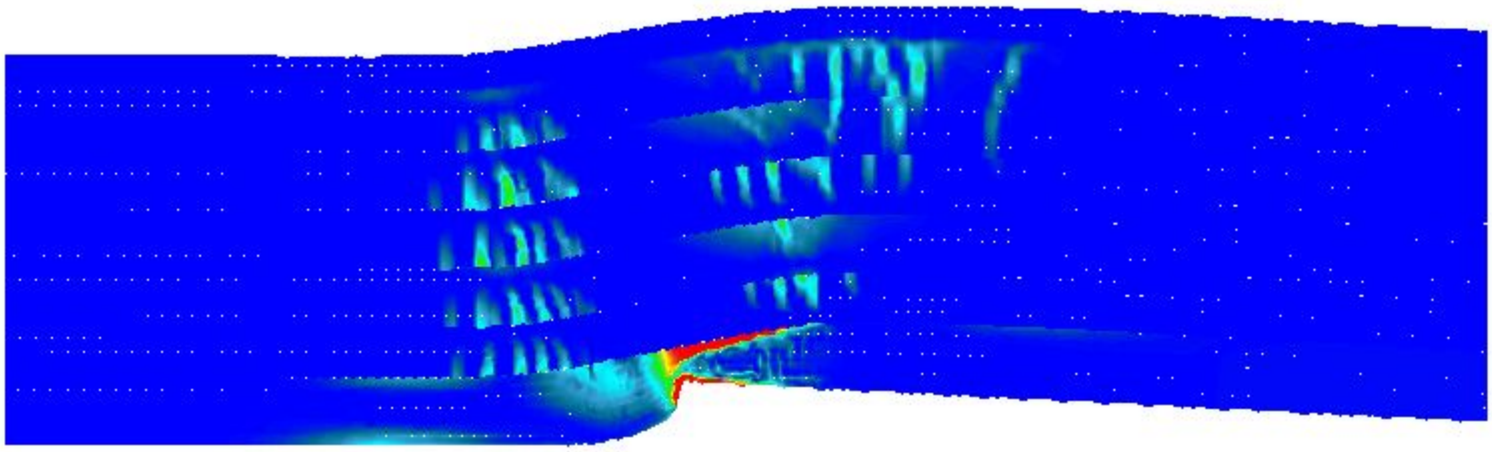
(Don't assume pin-lines for balancing)

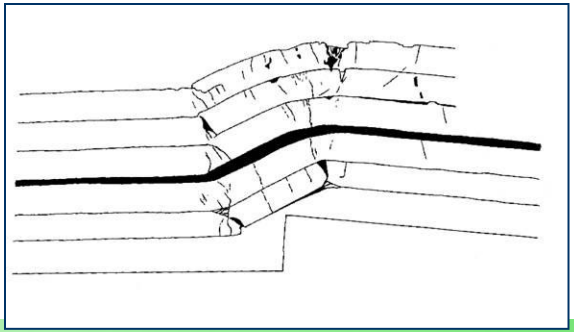
ε_x Strains Vary Along Layers



In these models, $e_x = e_{vol}$

Multi-Layer Numerical Simulations





Some conclusions

- The more experimental works – the less understandable the process (at least on this stage): ALL MODELS ARE WRONG

- Adding flexure sliding along buckled folds reduces brittle deformation drastically
- By opposite – fixing flexure (say by adding a dikes) will lead to the increasing of fracturing
- Volume-loss folds have a compressional solution bands crossing the beds which may cause fluid migration obstacle