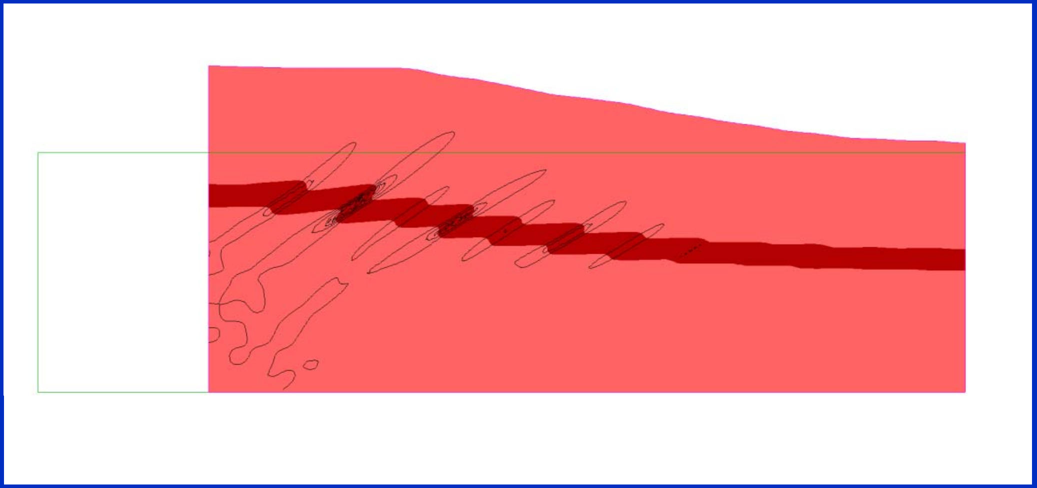
NUMERICAL EXPERIMENTS TO INVESTIGATE THE DYNAMICS OF TECTONIC PROCESSES



Previous focus on faulting

Some previous conclusions

[(1) Cundall, 1990; (2) Poliakov, 1999; (3) Hart, 2003]

1. Explicit, time-marching schemes used in FLAC & UDEC provides a method to follow the evolution of geologic systems (1,3).

2. No. of shear zones depends on $F = \sigma_{unload}/\sigma_{load}$

   $= p\sin\phi(\tan\phi-\sin\phi)/GV_{bc}/V_s$

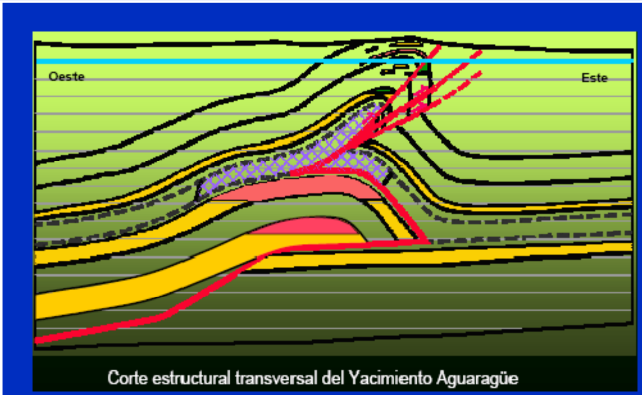
   p=initial hydrostatic pressure, V_{bc}=applied velocity, V_s=velocity of sound

   For F>100 close to quasi static (as experiments reported here)

   At low F, shear bands result from a complex dynamic interaction of elastoplastic waves (2)

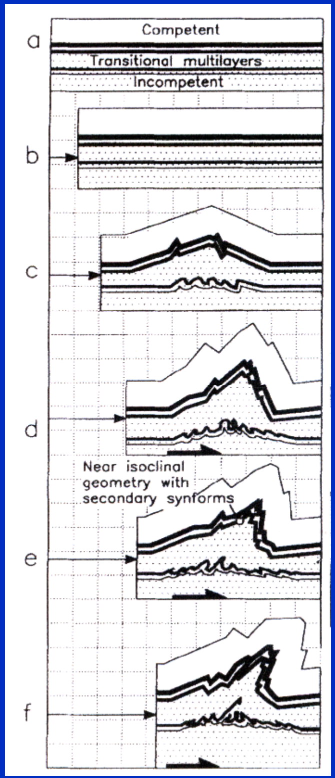
3. Slip is not monotonic on secondary faults (1)

Folding



Los estilos estructurales descriptos en superficie son aplicables por analogía a los modelos estructurales establecidos para el subsuelo.

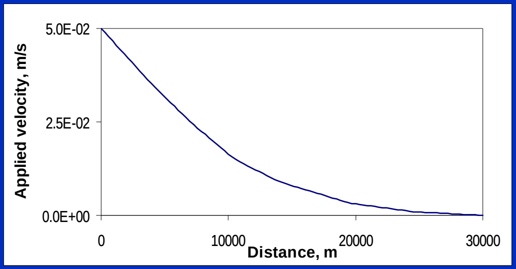
Asymmetrical structures thrust folds with underlying thrust faults in Argentina/Bolivia (Luquez et al., 2002)



Schematic evolution of detachment folds, Brooks Range, Alaska (Homza &

Wallace, 1997)

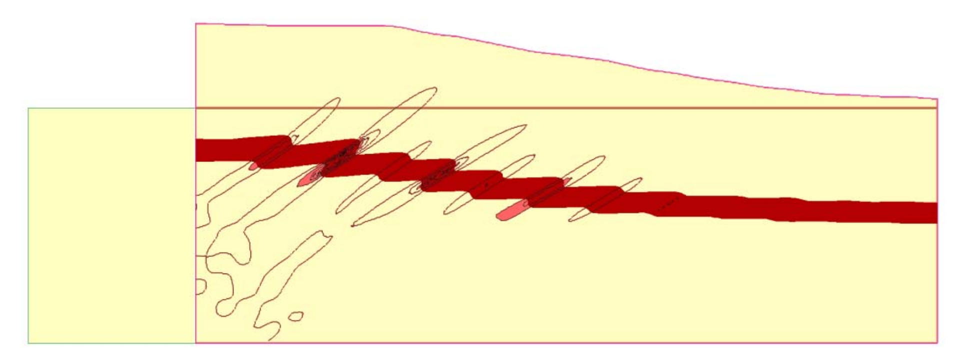
+



Basal velocity distribution

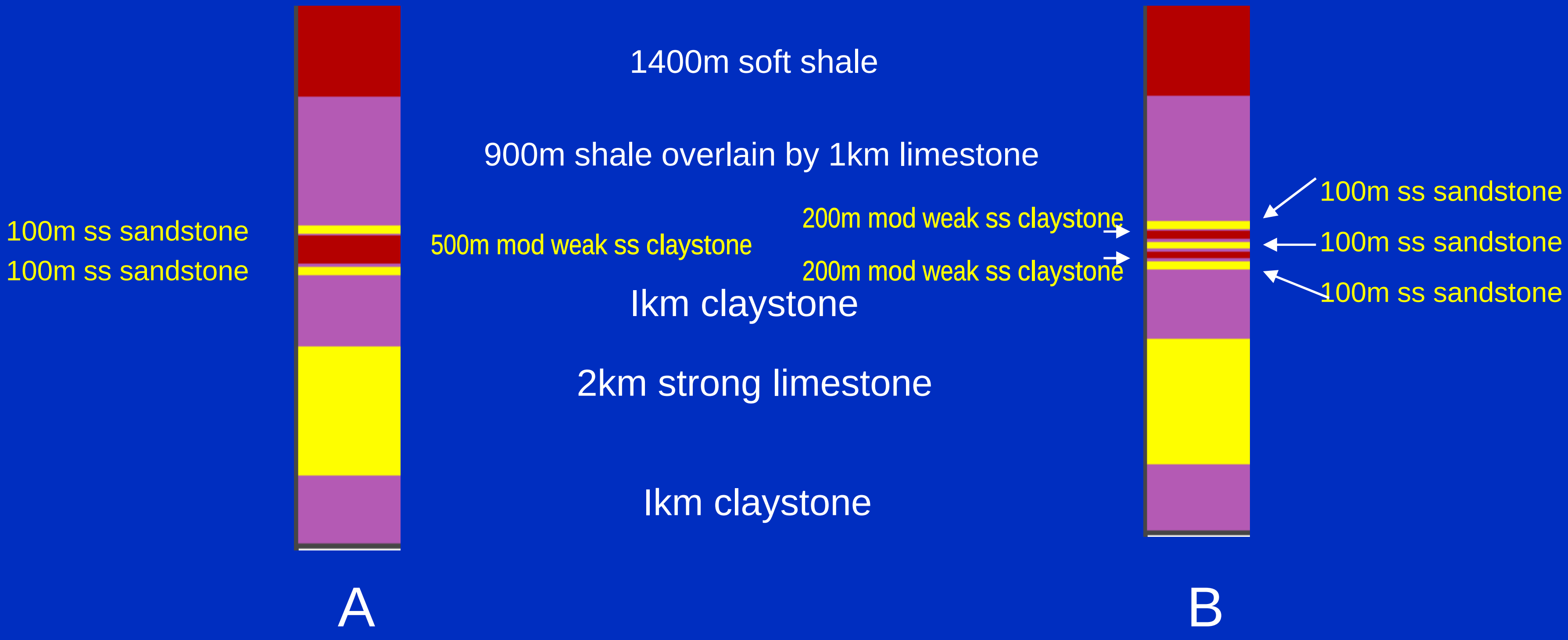
Applied velocities used here in FLAC for modelling asymmetrical structures (typically F≅100)

NUMERICAL EXPERIMENTS



Examples of modelled fold growth

2 models with different “reservoir” configurations



1400m soft shale

900m shale overlain by 1km limestone

100m ss sandstone

100m ss sandstone

500m mod weak ss claystone

200m mod weak ss claystone

200m mod weak ss claystone

100m ss sandstone

100m ss sandstone

100m ss sandstone

Ikm claystone

2km strong limestone

Ikm claystone

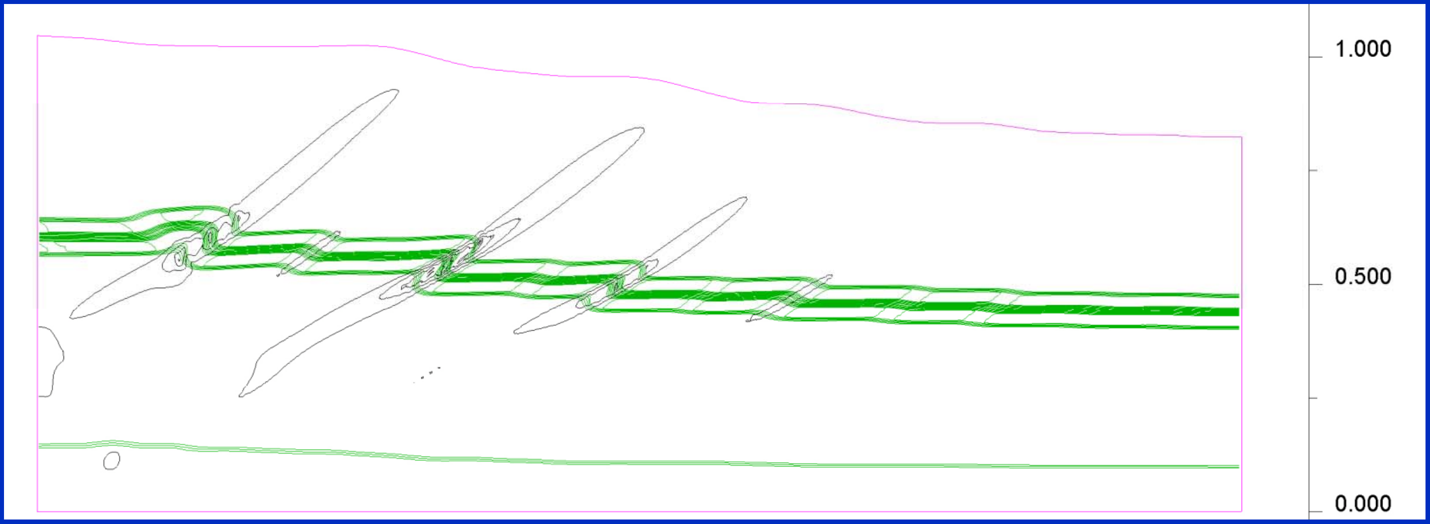
A

B

Total section: 8km

ss=strain-softening otherwise Mohr-Coulomb

Faults form with the asymmetrical folds



30 x 8km sequence with a 900m strain-softening sandstone-shale-sandstone sequence shortened 15%

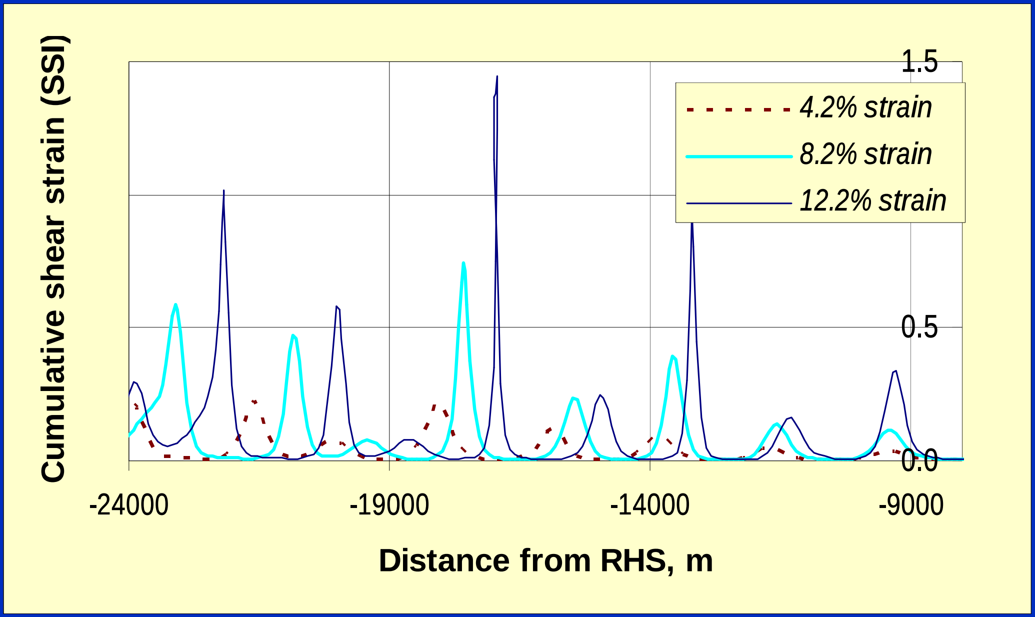
A quite simple model can reproduce the appearance (structural style) of asymmetrical folds with thrusts forming through forelimb

Subsequent results refer to M-C models with a strain-softening sequence as above

Structure evolution and shear strain rate

- Folds and faults grow with pulses of shear strain rate.
- These local periods of high SSR cyclically traverse the model, tending to dwell in certain positions.

Fault evolution



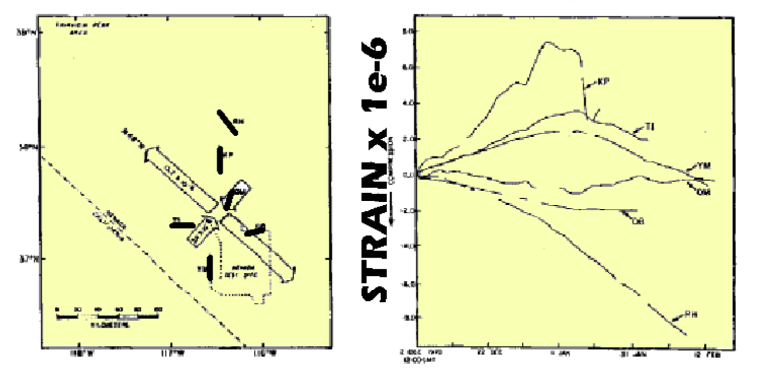
- Faults migrate wrt external coordinate frame
- Spacing varies with shortening
- Growth rates vary

QUALITATIVE EVALUATION OF THE DYNAMICS

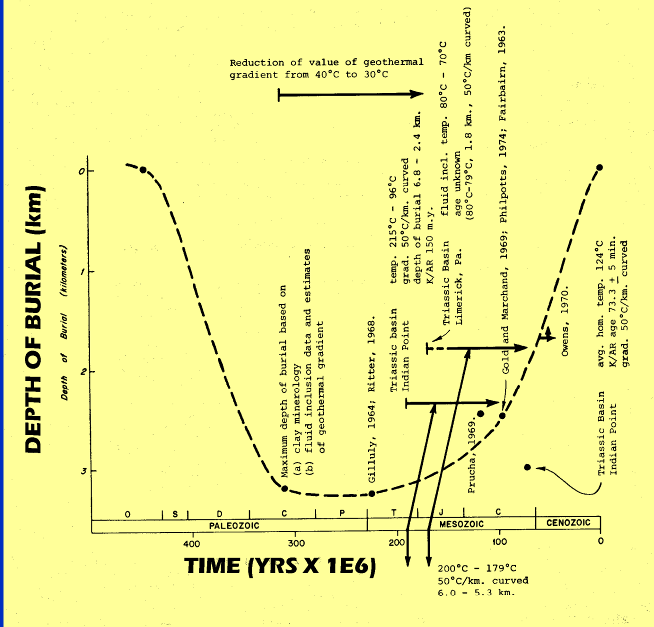
- What should we expect ?
- What do we see?

Fluctuation is characteristic of geologic processes

Strains around the Nevada Test Site for 2-month period (±9μS)

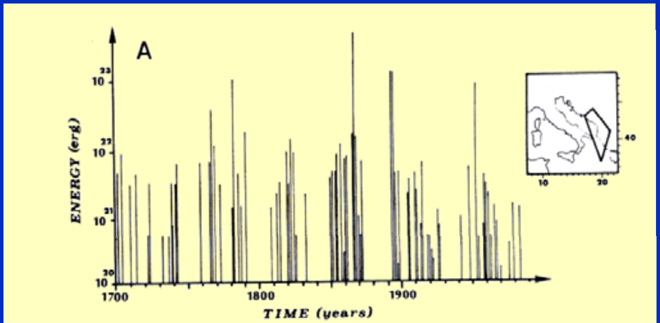


Smith & Kind, 1972



Appalachian basin burial & uplift ca 4km in 10^8 yrs

Harper & Szymanski, 1981

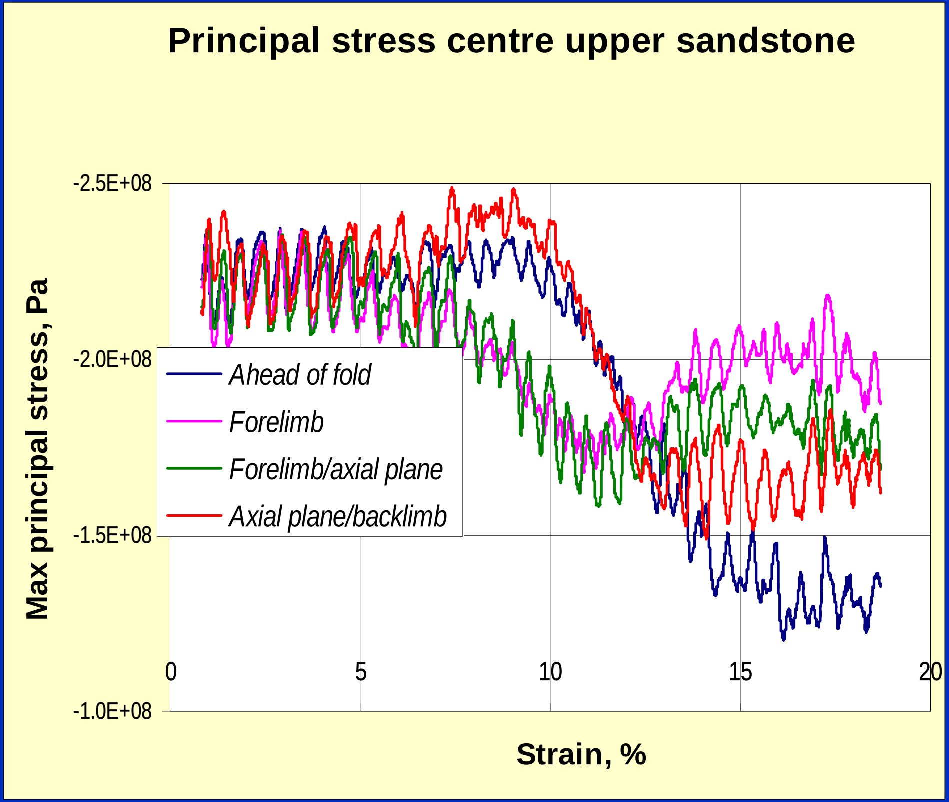


Seismic energy release along the Balkan front, 1700-1985. Mantovani et al., 1991

Waveforms during fold evolution: normal stress

Can plot parameters of interest against shortening strain $(l_1-l_0)/l_0$

- up to 15% fluctuation as stress changes with fold evolution (~30% maximum stress change)
- Varying complexity of waveform



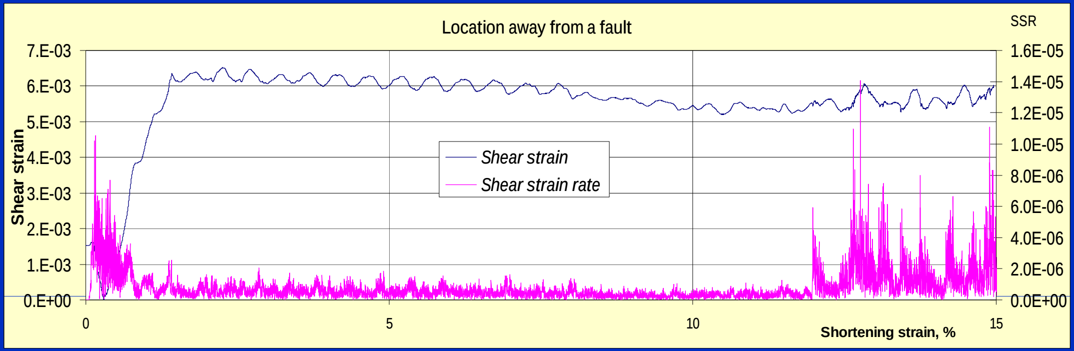
Mohr-Coulomb sequence; max V_{bc}= 0.05m/s

STRAIN OSCILLATION

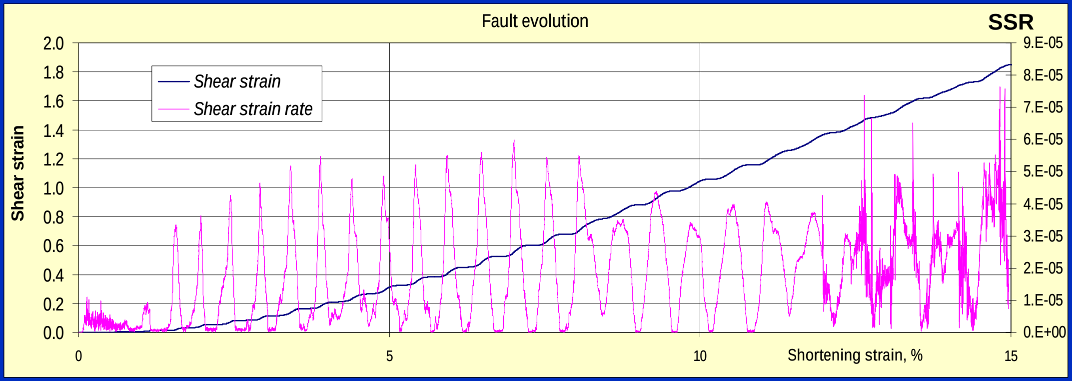
Values of all parameters typically oscillate e.g. shear strain rate

SSR pink

SSI dark blue



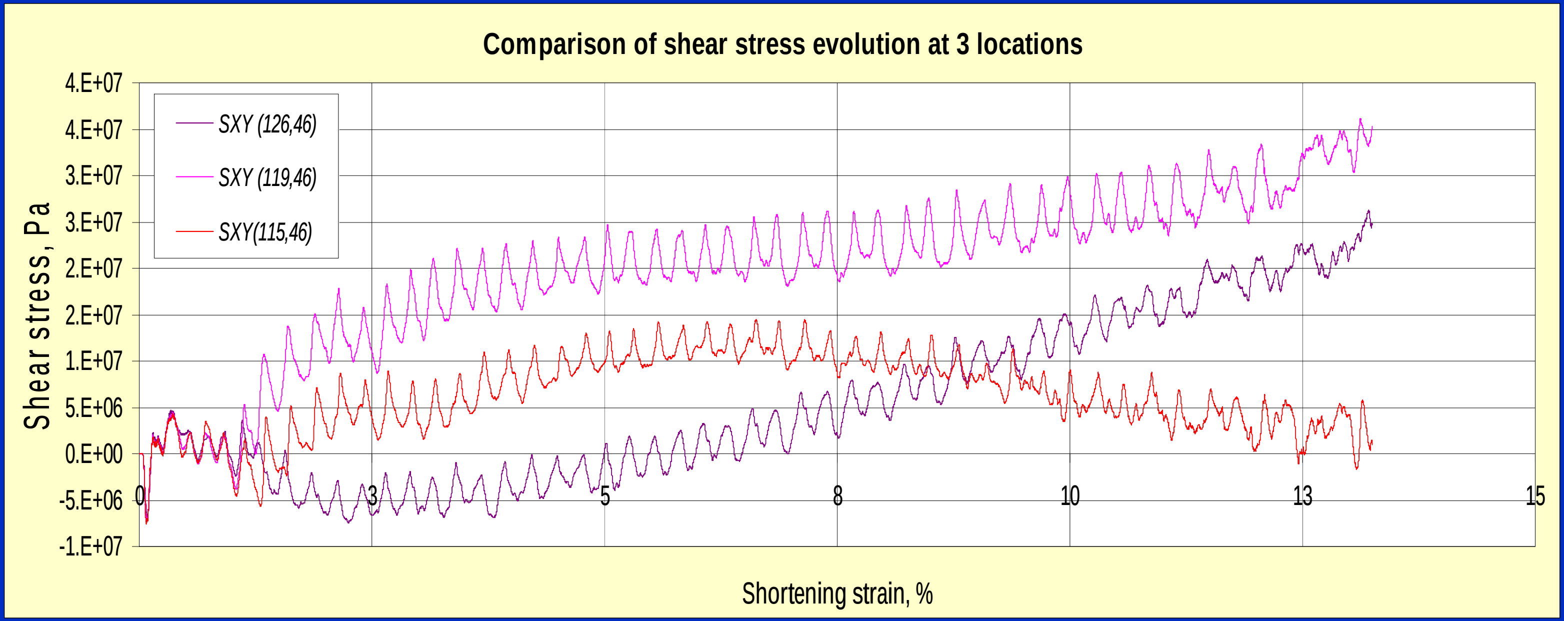
Outside fault/fold



Inside fault/fold

SHEAR STRESS:

FLUCTUATES & TRANSMITTED AS WAVES



Within and outside asymmetric fold

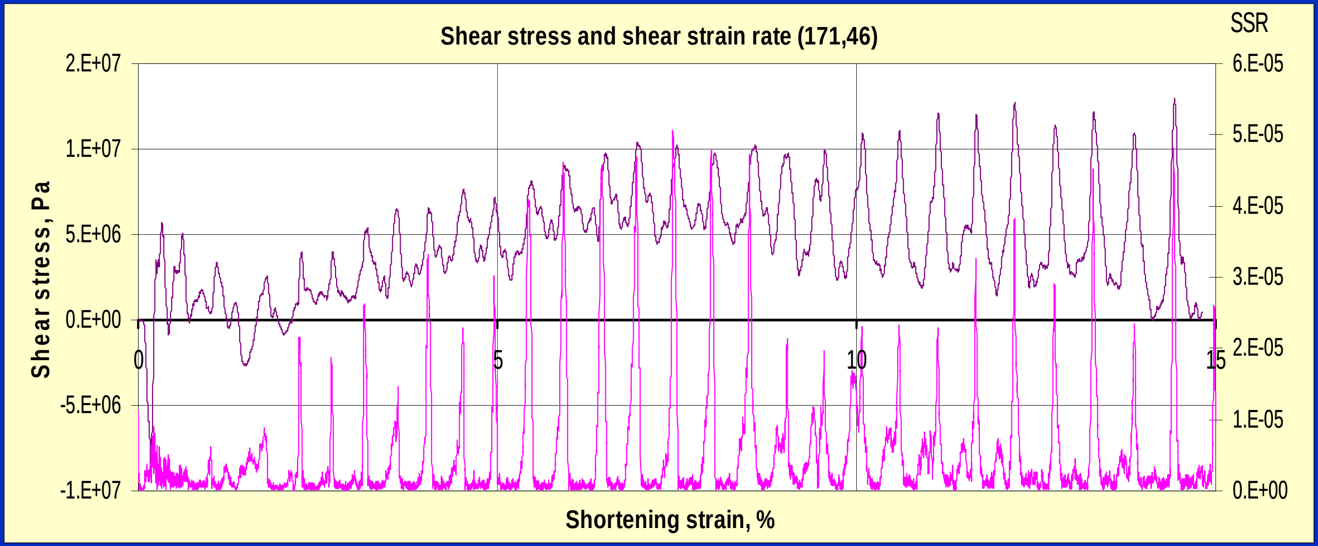
- stress transmitted throughout model in wavelike manner -different locations slightly out of phase
- Some tendency for a change from quasi-periodic (?) to chaotic behaviour as developing structures increase the heterogeneity

RELATION BETWEEN SHEAR STRESS AND SHEAR STRAIN RATE

- Typically a correlation between a build up of shear stress and an increase in shear strain rate
- Similar peaks of shear stress do not necessarily have a similar influence on shear strain rate

SSR pink

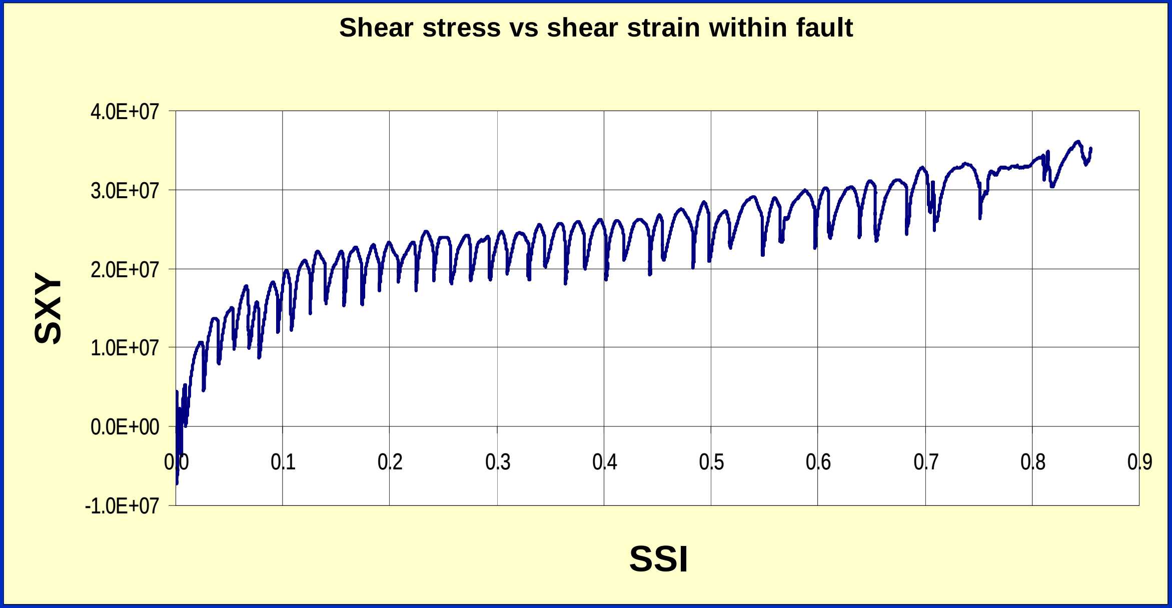
SXY plum



Fault zone

RELATION BETWEEN SHEAR STRESS AND SHEAR STRAIN

- Each cycle
  - Different
  - Asymmetric with SSI increasing throughout most but not all of the cycle
  - Variability increases with strain
- Apparent hardening
  - Increase of confining pressure
  - Rotation of stress trajectories



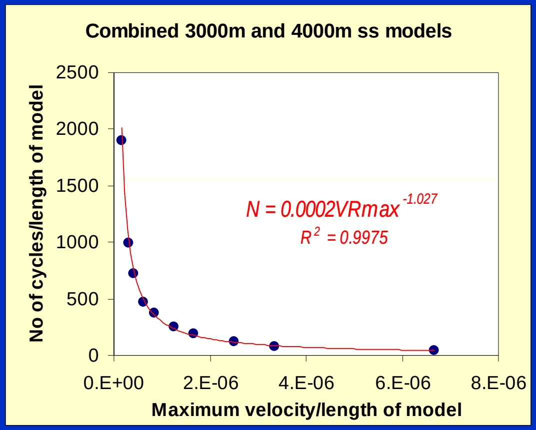
Fault zone

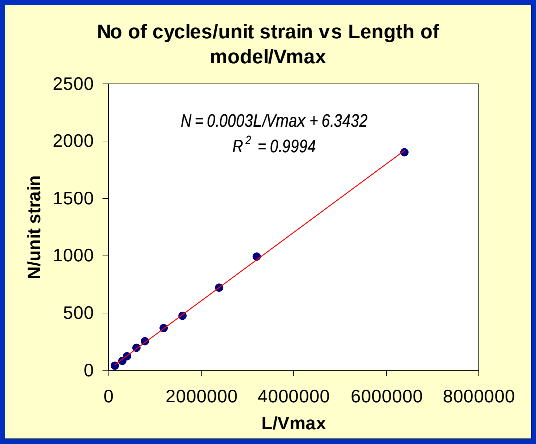
INFLUENCE OF MAGNITUDE OF APPLIED VELOCITY & MODEL LENGTH

SELECTING “QUASI PERIODIC” BEHAVIOUR:

- Both magnitude of applied velocity and model length affect wavelength of oscillations
- Normalising approximate wavelength and maximum applied velocity by model length results in a single power law
- f ~ 1/Vmax, as is F. Suggests that f may be a

$$f(\sigma_{unload}/\sigma_{load})$$


Combined 3000m and 4000m ss models


No of cycles/unit strain vs Length of model/Vmax

f = no. of cycles/unit strain

Some of the main observations

- Both natural geologic systems and the FLAC simulations of heterogeneous shortening which produce asymmetric folds are characterised by oscillatory motion.
- Models imply that stress passes through crustal materials in a wavelike manner. Fluctuations of most (mechanical) parameters occur of ca 5-15% of their total value.
- High rates of tectonic activity (high V_{bc}) lead to less frequent peaks (eg of shear stress) of higher magnitude
- Structural development increases heterogeneity and is typically associated with an increasingly chaotic waveforms
- Did not find an obvious relation between the nature of the dynamics and the finite (ultimate) geological structural style [most structures were asymmetric anticlines with thrust faults but for some combinations of material properties and sediment properties backthrusts (ie faults dipping in the opposite direction) developed].

Some concluding comments

- Stresses and strains characteristically exhibit oscillatory motions during structural evolution.
- The progressive growth of folds and faults closely follows these fluctuations. For this reason, these oscillatory motions should not be ignored in investigations of the precise mechanics of fault and fold growth. The waveforms are a sensitive and direct indicator of the (tectonic) system evolution.

Acknowledgements

Kes Heffer

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